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# Ecological Effects of Forest Fires in the INTERIOR of ALASKA

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# ACKNOWLEDGMENTS

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# ECOLOGICAL EFFECTS OF FOREST FIRES IN THE INTERIOR OF ALASKA [1]

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## INTRODUCTION

The area of Alaska is approximately 586,400 square miles (375,296,000 acres), including both land and water surfaces. Actual land area is approximately 572,555 square miles (366,435,000 acres). About 60 percent of the land area, or 219,861,000 acres, is in the interior.[3] In this vast area tree growth is the dominant vegetation on most of the land below an altitude of about 2,500 feet. However, in flat excessively wet lowlands, variously designated as muskeg, tundra, or bog, tree growth is absent or very scanty. Nearly 120 million acres bear sufficient tree growth to warrant designation as forest land. This great, predominantly coniferous, forest is analogous to the taiga of Siberia; its ecological counterpart is found throughout the boreal forest of northern Canada, the Scandinavian countries, and northern Russia. It represents a tremendous potential source of cellulose.

The forests of interior Alaska, as is true of all forests of the far north, are very susceptible to destruction by fire. Low precipitation, long hours of sunshine during the summer period, highly flammable ground cover, and coniferous forests, combine to make a high fire hazard. Most of the fires in the past were caused by man, who, in many parts of the north, tended to live a seminomadic life. Modern man appears to be even less careful with fire in Alaskan forests and as his numbers increase forest fires also increase. In addition, the forests of Alaska have also been subjected to fires caused by lightning. Once started, fires may burn for weeks or months, spreading over hundreds of thousands or even millions of acres. The reasons for the extensive spread of fires are numerous, among which may be mentioned lack of early detection, absence of effective natural barriers to spread, highly flammable fuel, inaccessibility, and insufficient man-power and equipment.

The study reported here, was undertaken during the summers of 1949 to 1952 to provide a better understanding of the ecological effects of forest fires in the Alaska interior. The information sought related primarily to the effects of forest fires on vegetation, but effects on

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[2] The author, Professor of Silviculture, Yale University School of Forestry, was employed by the Forest Service to carry out the study. It was sponsored jointly by the Forest Service, U. S. Department of Agriculture, and the Bureau of Land Management, U. S. Department of the Interior. The research was conducted under the supervision of R. F. Taylor, Forester in Charge, Alaska Forest Research Center.

[3] See section on geography of the Alaska interior.

soils, fur-bearers, big game, and to some extent on hydrology were studied also. Field work extended from the Kenai Peninsula on the south to the Yukon River Valley on the north (fig. 1).

Sample plots (usually 1/10 acre) and milacre quadrats were used to obtain information on species composition, size and age relations, density of cover, and successional trends in the various plant communities illustrative of the different stages of development following fires. Limited numbers of soil samples were collected and analyzed. These were obtained from recently burned areas and otherwise comparable areas long unburned. Tree stands were evaluated on 1/10-acre plots by tallying all trees 6 or more feet in height by diameter and height classes, and noting density of coverage for each height class or layer. At least five trees on each plot were measured for diameter and total height, and increment borings were obtained to establish age and rate of growth. Stand ages in the text and tables were determined at breast height. Most of the data were quantitative, but were supplemented by qualitative observations on succession, browsing by animals, fire history, and site conditions. Subordinate vegetation, including mosses and lichens, and tree seedlings, was investigated on milacre quadrats. Individual species were tallied by size classes and density of cover. Comprehensive collections of all plants, including mosses and lichens, were submitted to specialists for identification. These collections included 375 species of higher plants, 4 liverworts, 70 mosses, and 107 lichens. All together, data on 103 sample plots, 11 transects, and 860 milacre quadrats were recorded and analyzed.

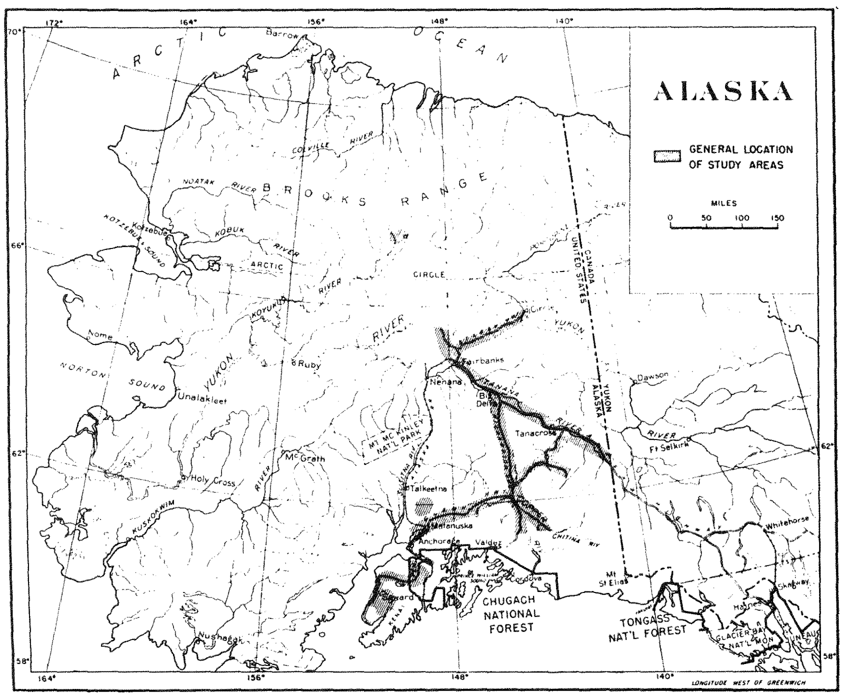


FIGURE 1.—Map showing location of study areas.

# INTERIOR OF ALASKA

The region referred to in this report as the Alaska interior includes all, or nearly all, the area within the commercial range of white spruce [4] in Alaska. It embraces the vast country between the Brooks Range on the north and the Coastal Range, bordering the Pacific Ocean on the south. Two major divisions may be recognized, one south of the Alaska Range and the other north.

## Geography

The Alaska Range, which sweeps northeasterly in a great crescent from the vicinity of Lake Clark on the west to the St. Elias Range on the east, forms the watershed between the Pacific drainage on the south and east and the Kuskokwim and Yukon Rivers on the west and north. It is 50 to 60 miles wide with many peaks exceeding 15,000 feet elevation and with extensive glaciers and snow fields. Mount McKinley, in the northwestern part of the great arc, with an elevation of 20,300 feet, is the highest mountain in North America.

The region between the Alaska Range and the mountains along the coast consists principally of the valleys of the Susitna, Matanuska, and Copper Rivers, and their tributaries. All these rivers, fed by glacial melt water, are choked with sediment.

The country north of the Alaska Range and south of the Brooks Range includes chiefly the valleys of the Kuskokwim, Yukon, and Tanana Rivers, and their tributaries. Mention may also be made of the Kobuk and Noatak Rivers, both of which drain into the Arctic Ocean. Brooks (*20*) [5] has described the Yukon and Kuskokwim province as a rolling upland "deeply dissected by well-developed drainage systems, with stream valleys and broad lowlands, and diversified by scattered mountain masses and isolated peaks that rise above the general level." In their courses through lowland areas the large rivers of the interior meander through numerous channels. With few exceptions they are heavily laden with silt derived from glaciers and from bank cutting.

Information on transportation and communication facilities, population and cities and towns may be found in Mid-Century Alaska, published by the Office of Territories, U. S. Department of the Interior in 1951 (*161*).

## Climate

The interior of Alaska has a continental climate with great extremes of temperature (table 1). During the winter much of the interior is characterized by relatively high atmospheric pressure and fair, cold weather. Aleutian low pressure systems may, however, move in over the Yukon Valley accompanied by southerly winds, moderated temperatures, and precipitation. Fair and unusually cold weather, with northerly winds, results when the Arctic high pressure system builds up. In the summer the great land mass of the interior heats up under the influence of the long days of high latitudes, and low atmos-

[4] For scientific names of Alaskan trees see Check List of Plant Species Collected, p. 104. Common names of trees, if available, are used in the text.

[5] Italic numbers in parentheses refer to literature cited, p. 95.

pheric pressure prevails. The weather becomes warm, and even hot, with occasional precipitation.

South of the Alaska Range the annual precipitation averages about 20 inches, with approximately 14 inches at Anchorage and 24 to 30 inches in the Susitna Valley. About one-third of the precipitation falls during the period May to August, most of it in July and August. The January mean temperature is around 10° F. and the July mean is about 57°. In the winter the temperature may drop to about −36° F. and in summer attain a high of 90°. The growing season is usually less than 90 days.

North of the Alaska Range, in the Yukon and Tanana River Valleys, the annual precipitation is less than 20 inches, commonly between 10 and 15 inches. About half of it falls during May to August, and within this period two-thirds during July and August. January mean temperature varies considerably from place to place; in some localities it is lower than −20° F. Mean temperature in July is about 60° F. In summer, temperatures as high as 100° F. are known and in winter they fall as low as −78°. The growing season varies from about 60 to 90 days.

TABLE 1.—*Temperature and precipitation in the Alaska interior* (*70*)

| Station | Temperature | | | | | Growing season | Precipitation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Length of record | January average | July average | Maximum | Minimum | | Length of record | Annual average | May–August [1] | September–April [1] |
| | *Years* | ° F. | ° F. | ° F. | ° F. | *Days* | *Years* | *Inches* | *Inches* | *Inches* |
| South of Alaska Range: | | | | | | | | | | |
| Anchorage | 22 | 11.2 | 57.0 | 92 | −36 | 110 | 22 | 14.32 | 5.35 | 8.97 |
| Kennecott | 24 | 4.5 | 52.4 | 80 | −39 | 91 | 20 | 21.60 | 8.04 | 13.56 |
| Matanuska | 19 | 12.6 | 57.7 | 91 | −36 | | 19 | 15.61 | 6.43 | 9.18 |
| Susitna | 6 | 9.1 | 57.7 | 86 | −37 | | 6 | 26.88 | 10.39 | 16.49 |
| Talkeetna | 19 | 7.6 | 58.0 | 90 | −48 | 72 | 18 | 30.03 | 11.38 | 18.65 |
| North of Alaska Range: | | | | | | | | | | |
| Allakaket | 24 | −20.3 | 57.7 | 90 | −70 | 54 | 25 | 13.10 | 6.10 | 7.00 |
| Dawson | 37 | −21.0 | 59.3 | 92 | −66 | | 37 | 12.69 | 5.34 | 7.35 |
| Fairbanks | 34 | −11.6 | 60.0 | 99 | −66 | 89 | 34 | 11.87 | 5.89 | 5.98 |
| Fort Yukon | 23 | −21.6 | 61.2 | 100 | −78 | 81 | 23 | 6.88 | 3.63 | 3.25 |
| Holy Cross | 35 | −0.4 | 56.5 | 93 | −58 | 90 | 29 | 20.06 | 8.46 | 11.60 |
| McKinley Park | 16 | 1.9 | 54.3 | 89 | −54 | 63 | 15 | 15.28 | 8.56 | 6.72 |
| Nulato | 13 | −7.5 | 57.5 | 90 | −62 | | 13 | 16.50 | 6.46 | 10.04 |
| Ruby | 6 | −7.5 | 57.5 | 98 | −52 | | 6 | 17.77 | 8.38 | 9.39 |
| Tanana | 37 | −12.5 | 58.3 | 91 | −76 | 64 | 38 | 13.63 | 6.94 | 6.69 |
| University Expt. Sta | 34 | −10.2 | 59.9 | 99 | −65 | | 34 | 11.76 | 5.88 | 5.88 |

[1] Total of average monthly precipitation.

Temperature and precipitation in interior Alaska are nicely balanced. A substantial increase in either, without a compensating increase in the other, probably would lead to less favorable growing conditions than exist today. Taber (*150*) described this as follows:

> The abundance of vegetation on perennially frozen ground in Alaska is partly due to low precipitation; for with the low temperatures, if the precipitation were high enough, most of the surface would be buried under snow and ice. Also, a rise in temperature, resulting in the thawing of the ground, and therefore better drainage, could convert much of it into a semi-desert unless the precipitation were also increased.

## Forests

The forests of the interior of Alaska represent one of the greatest renewable resources of the region. Potential production of wood cellulose is very great.

From the air the pattern of forest and other vegetation is a complex mosaic of types (fig. 2). In general, the forest occupies the valleys, often appearing as belts or ribbons along the streams, lower slopes, and low benchlands. Throughout most of the area the timberline is comparatively low, between 2,000 and 3,000 feet.

Fire is one of a number of factors responsible for the great complexity of the vegetation pattern. Only when the influence of past fires is recognized can one begin to account for the seemingly haphazard mosaic of vegetation. The sharp boundaries between stands of aspen or birch and white spruce are the edges of burns. The isolated stands of a few acres of white spruce, the upland stringers, and even the scattered trees are relicts of extensive stands that have been destroyed by fire. In many localities, areas that are now treeless formerly supported full forest stands that were destroyed by fire.

Another influence that contributed to the diversity of vegetation is the occurrence, in somewhat complicated pattern, of permafrost (permanently frozen ground). This phenomenon frequently results in poor soil drainage and poor soil aeration, restricted root space, and cold soil. Within the forested portions of the interior, either slow, impeded drainage (whether associated with permafrost or not) or excessive drainage result in outstandingly poor sites for tree

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FIGURE 2.—View of the Copper River Valley, showing a mosaic of forest types, white spruce, quaking aspen, and willow. This pattern reflects the complex fire history of the area.

growth. Sharp boundaries between vegetation types are most frequently caused by fire whereas those caused by topography and associated influences are apt to be diffuse.

The principal forested areas south of the Alaska Range include the following drainages, from east to west: the Copper River and its many large tributaries, the Matanuska River, the Susitna River and its tributaries, upper Cook Inlet, including the west side of the Kenai Peninsula, and the Iliamna Lake-Lake Clark and Nushagak River sections. The two last-mentioned sections drain into Bristol Bay and not into the Pacific Ocean. North of the Alaska Range, timber occurs extensively in the Tanana, Yukon, and Kuskokwim River regions. It is noteworthy that considerable areas of forest occur north of the Arctic Circle, as along the Porcupine and its tributaries, the Chandalar, the upper Koyukuk, and the Kobuk Rivers. Trees grow north of latitude 68° N. on the south slopes of the Brooks Range and as far west as the Niukluk River, near Council, on the Seward Peninsula; this is the westernmost occurrence of forest growth on the North American continent. In 1901 Collier (*34*) reported that spruce trees in this location attained diameters of 12 inches and heights of 50 feet. A treeless belt along the Bering Sea coast extends inland for as much as 150 miles. Locally, however, trees extend to the coast; Woolfe (*165*) reported finding dense groves of spruce within a quarter of a mile of the sea at Norton Sound. They were 6 to 10 inches in diameter and not over 40 feet in height.

Accurate data on the extent of the forested area of the interior will not be available until surveys are made. Current estimates are based on the opinions of experienced observers, rough maps prepared by foresters and others who have flown over the country, and reports of the Geological Survey and other governmental agencies. According to these estimates, about 120 million acres bear sufficient tree growth to warrant designation as forest land. Of this acreage, some 40 million acres are believed to be commercial or potentially commercial forest land. These lands now support (or did support before destruction by fire) fairly dense stands of white spruce, or successional stages leading to that type. Some 80 million acres of the interior bear sparse forests of open woodland. Accessibility and merchantability are concepts that foresters have learned to use with caution. In a modern technological world both can change quickly and drastically. Judged by present conditions, however, it may be estimated that about 14 million acres of the commercial or potentially commercial interior forests are presently accessible and more or less in use.

From time to time other estimates have been made on timber resources in the interior. In 1910 Kellogg (*69*) estimated that the interior forest north of the Alaska Range amounted to some 80 million acres. Thomas P. Riggs, Jr., early Governor of Alaska, who spent many years in the Territory as a member of both the Alaskan Engineering Commission and the International Boundary Commission, estimated that there were about 8,600 square miles, or 5,504,000 acres, of merchantable sawtimber in the interior and that this would average not less than 5,000 board-feet per acre (*56*). Riggs' estimate, by drainages, was as follows:

| River basin: | Merchantable sawtimber area (square miles) |
|---|---|
| Yukon Valley and small tributaries | 3,000 |
| Tanana Valley and small tributaries | 1,000 |
| Porcupine | 250 |
| Koyukuk | 500 |
| Nenana | 100 |
| Kantishna | 200 |
| Chandalar | 250 |
| Susitna | 300 |
| Kuskokwim | 1,000 |
| Kandik, Seventymile, Charley, Birch, Beaver, Tolovana, Chena, Delta, Innoko, Iditarod, etc | 2,000 |

Riggs included only one drainage (Susitna) south of the Alaska Range. Guthrie (*56*) stated that "the forests of interior Alaska are estimated to comprise not less than 150,000,000 acres."

The forests of the Alaska interior are analogous to, if not synonymous with, the taiga of Siberia. Hustich (*64*) stated that taiga was originally a Siberian word used for the boreal forest. He wrote, "The northern main forest types in the taiga seem to occur in the whole boreal forest region, in Canada, Alaska, and Eurasia. We know that the arctic and subarctic plants are mostly the same in the whole Arctic and Subarctic. Also their sociological affinity to each other is the same." According to Nuttonson (*103*) the term taiga "implies a coniferous northern forest with no admixture of nonconiferous species save the birch and aspen."

The principal forest types encountered are briefly discussed below and in detail in the section on Effect of Fire on Forests.

White spruce is the climax type on well-drained soils. When destroyed by fire the same species may be reproduced at once but more commonly Alaska paper birch or quaking aspen comes in. These two species often occur in essentially pure stands but mixtures are also well known. As succession progresses, white spruce enters the birch and aspen stands and finally assumes a dominant position as the shorter lived birch and aspen drop out. Balsam poplar, the common cottonwood of the interior, is usually found on recent alluvium along streams and on flood plains. On poorly drained forested sites, black spruce is invariably dominant. Locally this species may appear on uplands, forming pure stands as a "fire type." Some formerly forested upland areas have been burned so severely and so frequently that they are now treeless or nearly so. Close examination often discloses relicts of spruce (charred stumps, portions of boles, etc.) in areas now supporting only grass and fireweed or shrubby willows.

The view is sometimes expressed that the trees of the interior are all small and scrubby, and that their growth is excessively slow. This generalization is wholly unwarranted (fig. 3) and probably is based on observations along roadsides where burning has usually been most frequent. There are many references to timber conditions in the reports of early explorers in the Territory, chiefly in those of the Geological Survey. A series of reports on maximum sizes of spruce trees and on the position of the timberline have been compiled in table 2.

The timber seen by the early explorers was more indicative of potentialities than are the modern forests, which have suffered severely

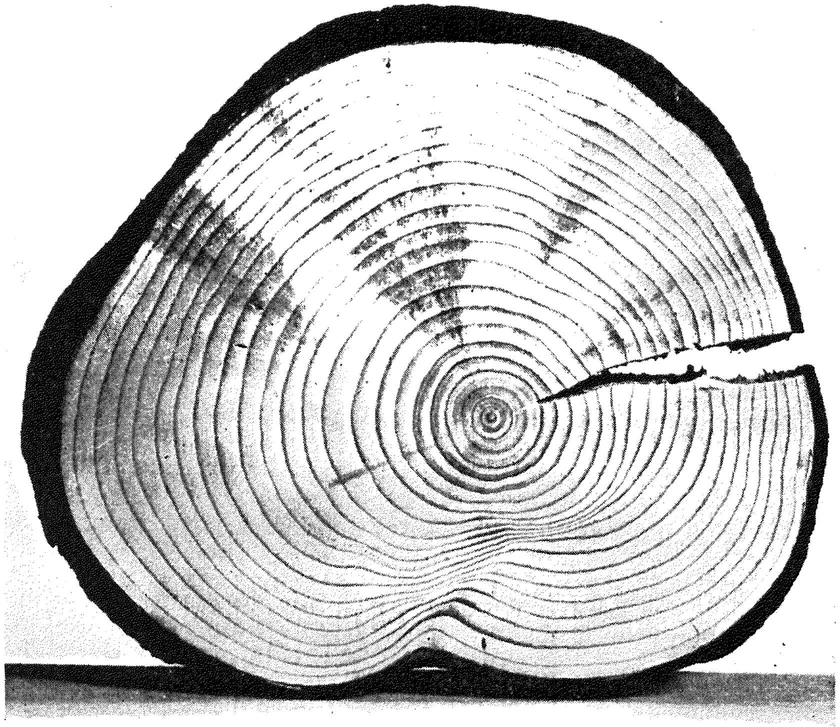

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FIGURE 3.—A cross section of 6-inch d. b. h. white spruce, showing 24 annual rings. The ring width shows remarkably good growth. Vicinity of Kasilof, Kenai Peninsula, 1949.

from fires during the past half century. Diameters of 18 to 24 or more inches were commonly reported by early explorers. Even north of the Arctic Circle, on the headwaters of the Porcupine River, Robert Kennicott (*33*) found spruce 36 inches in diameter, and in 1901 Schrader (*137*) reported spruce exceeding 24 inches in diameter in the Chandalar-Koyukuk region. South of the Alaska Range, in a grove of spruce on the Kakhtul River (a tributary to the Mulchatna River) Schanz (*135*) in 1893 measured nine trees, each of which was over 3 feet in diameter.

Learnard (*76*) in 1898, on his trip up the Susitna River, cut a tree that furnished sufficient lumber for a boat 35 feet long and 5 feet wide at the bottom. He wrote, "At Croto Creek [now called Deshka River], where the boat was built, no difficulty was experienced in finding a spruce tree from which ten planks were sawed which were 35 feet long and average 11 inches in width. Many other trees were seen fully as large as the one cut for the boat."

On 58 sample plots with spruce of merchantable size, the average volume per acre was 2,400 cubic feet (trees 5 inches in diameter and larger to a 4-inch top) or about 8,000 board-feet (trees 7 inches in diameter and larger to a 6-inch top, Scribner rule). The average age

TABLE 2.—*Maximum spruce size and elevation of timberline reported by various explorers*

| Region | Observer | Maximum size of spruce | | Elevation of timber-line |
|---|---|---|---|---|
| | | Diameter | Height | |
| South of Alaska Range: | | *Inches* | *Feet* | *Feet* |
| Kakhtul River | Schanz (*135*) | 36+ | | |
| Mount Spurr | Capps (*27*) | 30 | | 2, 300 |
| Lower Skwentna River | Capps (*29*) | 24 | | 2, 000 |
| Willow Creek-Kashwitna River | Capps and Tuck (*30*) | 36 | | 1, 800-2, 000 |
| Chulitna River | Capps (*26*) | | | 2, 000-2, 500 |
| Talkeetna River | Capps (*26*) | 24 | | 2, 000 |
| Tonsina River | Moffit (*98*) | | | 3, 000 |
| Copper River | Schrader and Spencer (*138*). | 36+ | | 3, 000 |
| North of Alaska Range: | | | | |
| Alaska Range | Eldridge (*42*) | | | 3, 000 |
| Tanana-White Rivers | Brooks (*19*) | 24 | | 3, 400 |
| Upper Tanana River | Pearson (*111*) | 18 | | |
| Big Tok River | Rice (*129*) | 24+ | 100 | |
| Yukon-Tanana Rivers | Mertie (*95*) | | | 2, 000-3, 000 |
| Coal Creek | Osgood (*107*) | 19. 7 | 80 | |
| Fortymile River | Barnard (*9*) | 22 | 100 | 3, 000-3, 200 |
| Tatonduk-Nation Region | Mertie (*94*) | | | 2, 500-3, 000 |
| Chandalar-Koyukuk Region | Schrader (*137*) | 24+ | 100 | |
| Sheenjek River | Mertie (*93*) | 24 | | 2, 000-3, 000 |
| Porcupine-Yukon River | Cairnes (*23*) | 18 | | 2, 900 |
| Headwaters of Porcupine River | Kennicott (*33*) | 36 | | |
| Kobuk River | McLenegan (*88*) | 24 | | |
| ¼ mile from Norton Sound | Woolfe (*165*) | 10 | 40 | |
| Niukluk River, near Council, Seward Peninsula. | Collier (*34*) | 12 | 50 | |

was about 120 years. Rotation age might be about 160 years and at that time the average diameter of the trees would be 8 to 12 inches. At 160 years the better spruce stands would average perhaps 3,900 cubic feet or 15,500 board-feet per acre. Indications are that at the rotation age suggested 80 percent of the trees in the stand would be 5 inches in diameter and larger and 20 percent would exceed 12 inches in diameter. Some of the trees would have attained diameters of 18 to 20 inches.

On the 40 million acres of commercial or potentially commercial interior forest land there is estimated to be about 32 billion cubic feet or 180 billion board-feet of white spruce, Alaska paper birch, aspen, and cottonwood. Volumes on the 80 million acres classed as woodland are purely conjectural.

Even if current estimates of timber acreage and growth and yield in the interior prove to be too high, the forest resource will still be so tremendous and so important to the future economy of Alaska that it must receive full consideration in the national program of forest conservation.

## HISTORY OF FOREST FIRES IN INTERIOR ALASKA

Forest fires are well known throughout the timbered regions of the far north. Their extensive and repeated occurrence in prehistoric, historic, and modern time (fig. 4) is well substantiated. The record of fire occurrence in prehistoric time can be read in the forests themselves; the journals and reports of explorers and travelers continue the record to modern time.

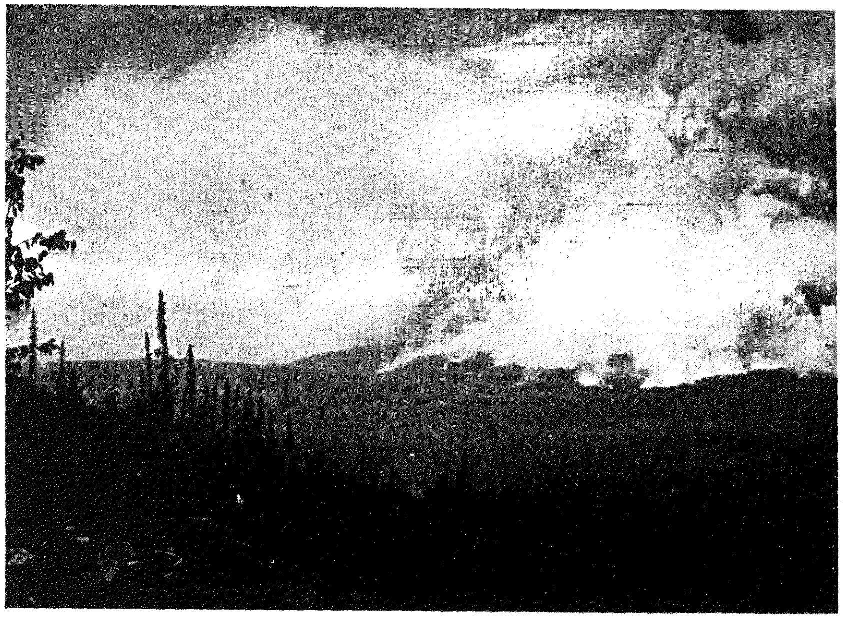

FIGURE 4.—Yankee-Ophir Creek fire, WNW of McGrath in the Kuskokwim River region. This fire covered an area of about 175,000 acres, 1941. (Photo by Bureau of Land Management, U. S. Department of the Interior.)

Forests of the north are especially liable to destruction by fire. Relatively low precipitation, long hours of sunshine during the summer period, and remarkably high air temperatures increase the fire hazard in forests which, by their very nature, are readily flammable. The northern forests are characteristically coniferous with comparatively small trees, often supporting a heavy growth of beard lichens. Fire carries readily in dense stands as it also does in open stands; in the latter the trees retain their branches to the ground and the intervening spaces are blanketed with a cover of mosses, lichens, and small shrubs, commonly ericaceous. In the summer the mosses and lichens become extremely dry and tinderlike.

In 1889 Bell (*11*) described forest fires in northern Canada as follows:

> The trees are crowded so closely together that their branches touch or intermingle. The ground is deeply covered with dry moss. After prolonged hot weather and drought the moisture becomes thoroughly dried out of the gummy leaves and branches, leaving the resin and turpentine ready for ignition. All the conditions are now present, and only await a spark of fire to give rise to one of the wildest scenes of destruction of which the world is capable. When the fire has once started, the pitchy trees burn rapidly; the flames rush through their tops and high above them with a roaring noise. Should the atmosphere be calm, the ascending heat soon causes the air to flow in, and after a time the wind acquires great velocity. An irresistible front of flame is soon developed, and it sweeps forward, devouring the forest before it like the dry grass in a running prairie fire, which this resembles, but on a gigantic scale. The irregular line of fire has a height of a hundred feet or more above the trees, or two hundred from the ground. Great sheets of flame appear to disconnect themselves from the fiery torrent and leap upward and explode, or dart forward, bridging over open spaces, such as lakes and rivers, and starting the fire afresh in advance of the main column, as if impatient of the slower progress which it is making. These immense shooting flames are probably due to the large quantities of inflammable gas evolved from the heated tree tops just in advance of actual combustion, and they help to account for the almost incredible speed of some of the larger forest fires, one of which was known to run about 130 miles in twelve hours, or upwards of ten miles an hour.

Bell's description was based on experience gained during more than 30 summers spent in northern forests.

Extensive fires in northern forests are not peculiar to Alaska. Northern Russia and Siberia have experienced the scourge of forest fires down through the years. Middendorff (*96*) in his 1867 report of his famous journey to northern and eastern Siberia repeatedly commented on the extensive fires encountered and the even more extensive evidence of past fires. He passed through "hundreds and thousands of square *versts* which fire had destroyed" (verst=1.067 km. or 0.6629 mile). In 1917 Pohle (*119*) stated that in northern Russia, as in Siberia, forest fires occur year after year as a result of the carelessness and imprudent conduct of the people. Prasolov (*121*), in discussing the soils of the Urals and east Siberian upland in 1932, wrote as follows: "The bogs and wooded swamps are the principal obstacles to travel in these northern forests, together with the great quantity of burnt fallen timber that covers the ground, the so-called *gari*. This fallen timber makes up the normal landscape of the region; it is difficult to find any wood untouched by fire." Perhaps the most readily accessible account of forest fires in Siberia is that of Shostakovitch (*145*) in 1925. He described the particularly bad fires of 1915, which were estimated to have destroyed the forest over an area of 55,000 square miles, an area equal to about one-third of western Europe (excluding Russia). Smoke from these fires spread over an area of some 2,632,000 square miles, about equal to the whole of Europe and over four times the area of Alaska. Some of these fires in Russia and Siberia resulted from lightning but most were caused by man (*145*).

The forests in the northern parts of the Scandinavian countries have also experienced repeated fires. For example, Rubner (*132*) stated in 1927 that in northern Finland, almost all of the forests bore traces of fire.

Conditions in northern Canada are similar to those in a large part of Alaska. In 1889 Bell (*11*) stated that "Notwithstanding its immense extent, it may be said that fire has run through every part of it at one period or another." The journals of Samuel Hearne and Philip Turnor, written between 1774 and 1792, included reports of extensive fires in Canada (*158*). On July 14, 1774, Hearne made the following entry in his journal: "Most of the woods which we came by for these 2 Days Past have formaly ben set on fire, as ware also in many other Parts as we came along." On July 30, 1781, Turnor

wrote of "the Land rather bold with Woods now on fire." In 1843 Davies (*36*) expressed the view that "fires . . . have ravaged the whole country. Indeed, there can be but little doubt, that one time nearly, if not the whole, of the interior of Labrador was covered with wood, which has since been destroyed by fire."

Various Canadian writers have regarded Indians as a major cause of forest fires in earliest time. Davies (*36*) in 1843 and Low (*83*) in 1896 reported that Indians started fires for smoke signals and believed that the signal fires were responsible for burning much country. General carelessness of Indians with campfires, especially when not on or near their own hunting grounds, was also regarded by Bell (*11*) in 1889 and Low (*83*) in 1896 as a major source of forest fires. But the full burden of responsibility for forest fires cannot be placed on Indians. Bell's list of those who share the responsibility is rather complete: "These include fur traders, missionaries, surveyors, explorers, prospectors, etc. and, nearer to civilization, railway builders, common-road makers, lumbermen, bush-rangers, and settlers." Raup and Denny (*126*) reported that along the southern part of the Alaska Highway stands that do not show some effects of fire are rare.

Perhaps the earliest written record of a forest fire in Alaska is that of the Russian mining engineer Doroschin (*37*) who, in 1850, ascended the Kenai River in search of gold. He reported that he could not complete his investigations because of a forest fire that he encountered. In the years that followed acquisition of Alaska by the United States, exploration was extended and references to forest fires became increasingly frequent.

Allen (*5*) encountered extensive fires on the upper Tanana River. In 1885 he reported,

> Heavy smoke, caused by extensive timber fires, obscured the sun the entire day, so that an observation was impossible. This smoke had originated from signal fires which were intended to give warning of our presence in the country. When we first arrived at Nandell's there was only an occasional smoke around, but as his guests departed for their different habitations each marked his trail by a signal fire. The prevailing wind was from the east and carried the smoke along with us. In answer to the fires on the south bank new ones started on the north, so that for nearly two days we barely caught a glimpse of the sun except through the heavy spruce smoke.

Glave (*49*), on an extensive hunting trip, wrote in 1892 that "Miles and miles of blackened stumps marked the ravages of forest fires." In 1894 Schwatka (*140*) reported that "Evidences of conflagration in the dense coniferous forests were everywhere frequent . . ." on the upper Yukon. He also stated that "Ahead of us there still hung dense clouds of smoke which seemed as if the whole world was on fire in that direction."

In 1898 Abercrombie (*3*) encountered large fires in the vicinity of the head of Klutina Lake. He stated,

> I noticed that there was quite a mound of petals under each spruce tree, the branches coming close to the ground. When a fire had eaten its way to one of these trees through the moss, the petals would ignite and the fire, rushing up the tree with a roar, would create a flame 150 feet high. This would send forth a shower of sparks that would start thousands of additional fires, each to repeat the operations of the first. The entire valley seemed to be on fire, which made travelling through the timber very dangerous, as the falling trees were liable to injure man or beast, if they did not stampede the entire pack train.

On his journey to the Tanana River in 1898, Glenn (*50*) traveled through the country north of Bubb Creek, a tributary of the Tazlina River. He recorded, "We entered what we called the 'burned district,' which seemed to extend as far as the country is visible toward the Copper River, and to the northward almost to the Alaska Range."

The statements quoted above were made by trained observers engaged in serious exploration. They supply indisputable proof that, even prior to the entry of white men in numbers, the forests of the Alaska interior were ravaged by fires.

In earliest times fires were caused, as they are today, by lightning, but there can be little doubt that Indians were the major cause. The habit of using signal fires as a primitive means of communication was evidently widespread throughout the northern forests of America. References to this practice in eastern Canada by Davies (*36*) in 1843 and Low (*83*) in 1896 have already been cited. The practice was reported in Alaska by the following early writers: Schwatka (*139*, *140*), Allen (*5*), Glave (*49*), Haskell (*57*), and Learnard (*76*). Glave (*49*) in 1892 observed the practice in operation and wrote of his Indian guide, Nanchay, "He began an incessant signalling by burning trees, and by and by the keen eyes of Tsook [the son of the guide] spied a faint curl of smoke creeping up from the wooded brow of a hill about ten miles away, which told of the whereabouts of the missing family."

In addition to the use of fire for signalling, the Indians also employed smoky fires to protect themselves from mosquitoes (*49*, *57*). They set general fires to drive mosquitoes and gnats out of the country (*5*, *140*) and to burn out dense undergrowth so they could see large game as it passed over the burns (*3*).

Carelessness with campfires must also be reckoned as an important source of fires in the early days. Bell (*11*) in 1889 remarked, "It gives them some trouble to put out a fire completely when they leave a camp, or where they may have stopped to cook a meal or gum their canoe by the way, and an Indian will seldom do anything except by necessity."

The tempo of forest destruction in Alaska was substantially increased after gold was discovered in the Klondike in 1896. The fabulous stampede that followed brought thousands of people to the Yukon and to Alaska. From 1898 on to 1939, when the Alaska Fire Control Service was organized within the General Land Office of the U. S. Department of the Interior, tremendous acreages of forest land were burned nearly every year. The tragic record of resource waste during this period may be found in contemporary reports and on the face of nearly every landscape. It is not feasible to present here a detailed record of the destruction suffered by the interior forests since the gold rush, but attention will be directed to sample testimony. Those interested will find abundant material on forest fires, their causes, extent, and destruction in the writings of Rohn (*130*, *p. 414*), Brooks (*19*, *p. 489*; *20*, *p. 42*; *21*, *p. 206*), Moffit and Stone (*99*, *p. 50*), Kellogg (*69*), Graves (*53*), Guthrie (*56*), Drake (*38*), and Moffit (*98*).

Few men have had the intimate personal knowledge of Alaska that was possessed by the late Alfred Hulse Brooks of the Geological Survey. This keen observer (*21*) stated in 1911:

> In the inland of the province the supply of timber at best is rather scanty but would probably be sufficient for local use were it not subjected to ravages by forest fires nearly every year. Such fires occur on both sides of the Alaska Range, but especially in the Yukon basin, where the semiarid conditions often allow the forest fire to sweep over miles of territory until it is stopped by a watercourse too wide to be crossed. It is no exaggeration to state that hundreds of square miles of timber have been burned off the Yukon basin during the last decade. This burning of timber is in part done purposely by both whites and natives in order to get rid of insect pests or to improve the growth of grass near their habitations, and is in part due to carelessness. The writer has traced at least one forest fire to a native camp. But the amount of timber annually destroyed by the natives is small compared with that for which the whites are responsible. Many a white man has deliberately started a forest fire which swept over miles of country, solely that he might obtain a few acres of dry wood for winter use. If this willful waste does not stop, the time is not far distant when there will be a scarcity of timber even for local use. Timber grows very slowly in this northern field, and once destroyed it probably cannot be replaced for several generations. It appears to the writer that at the present rate of consumption and destruction by forest fires the timber of the Yukon-Tanana region will not be sufficient for the placer-mining industry, let alone any possible development when this stage has been passed.

Graves (*53*), after a visit to the interior in 1915, reported, "The interior forests of Alaska are being destroyed at an appalling rate by forest fires. Conditions existing in the western United States 25 years ago are repeating themselves in Alaska." Moffit (*98*), writing of the Tonsina district, mentioned several of the common reasons given for burning the forest. He concluded, "Yet in spite of any benefits that may have been involved in the practice, it is true that much of a valuable resource was destroyed beyond the hope of early replacement, for trees in the north country grow slowly."

The acreage of forest land in Alaska burned annually from 1898 to 1939 is not known but it probably averaged more than 1 million acres. During single bad fire years, as for example 1915, several million acres were burned.

Annual fire losses recorded from 1940 through 1945 by the Alaska Fire Control Service and from 1946 to 1954 by the Bureau of Land Management, U. S. Department of the Interior, are as follows:

| Fire season: | Forest land burned (acres) | Fire season: | Forest land burned (acres) |
|---|---|---|---|
| 1940 | 4, 500, 000 | 1948 | 35, 190 |
| 1941 | 3, 654, 774 | 1949 | 18, 147 |
| 1942 | 452, 510 | 1950 | 2, 063, 983 |
| 1943 | 666, 773 | 1951 | 221, 669 |
| 1944 | 110, 604 | 1952 | 74, 690 |
| 1945 | 117, 313 | 1953 | 472, 549 |
| 1946 | 1, 438, 963 | 1954 | 1, 430, 645 |
| 1947 | 1, 431, 665 | | |

Over this 15-year period the average acreage burned during each fire season was approximately 1.11 million acres. During the first two years covered by the record, the Alaska Fire Control Service was in the process of organization, assembling equipment and personnel. These were also years with dry fire seasons and mining was in progress throughout Alaska. Fire prevention education was in its infancy. The marked decline in fires during the war years, 1942–45, is probably the result of a combination of circumstances. Mining activities ceased, nearly all civilian travel to the Territory was restricted and a large portion of the widely scattered population was drawn to construction centers.

In 1946 and 1947 there was a return to civilian activities, a dispersal of the population, and an influx of settlers and others. The remarkably small acreages burned in 1948 and 1949 reflect the wet conditions during the fire seasons of those years. The large area burned in 1950 was due primarily to the great fire of some 1,800,000 acres in the vicinity of Fort Yukon. Although drought conditions prevailed in the Territory in 1951, the acreage burned was relatively modest. This commendable record evidently reflects the increasing efficiency of the fire control organization of the Bureau of Land Management.

The following notes on some of the larger fires were made available through the courtesy of R. R. Robinson, Area Forester, Bureau of Land Management, U. S. Department of the Interior.

**1893** A fire near the town of Knik burned about 135,000 acres.

**1896** Fires started by miners in the local gold rush burned along the entire length of Canyon Creek (in the Sunrise area); 34,000 acres were burned.

**1915** The Sourdough Hill fire, presumably set by sparks from the Copper River and Northwestern Railroad, burned from Chitina to the Kennicott River and from the Chitina River to the mountains on the north; 384,000 acres were burned.

The Kennecott fire, presumably set on a windy day by one man using oil-soaked rags, burned all the timbered country between the Kennicott and Nizina Rivers. This fire was reportedly set to kill the timber so as to provide fuelwood for sale at the Kennecott mine; about 64,000 acres were burned.

**1920** Middle Fork of the Chandalar River fire. This started on the East Fork and burned across to the Middle Fork, covering a tract about 15 miles wide and 12 miles long; 115,200 acres were burned.

**1922** Mosquito Fork Flat fire. This fire burned all of the Mosquito Fork watershed; it started 6 miles west of Long Cabin on the old Valdez-Eagle trail on the divide between Permission and Mosquito Creeks. The area covered was about 48 miles long by 30 miles wide; 921,600 acres were burned.

Salmon Village fire. This fire burned about 448,000 acres on the Black River and Porcupine River.

**1924** Foraker Creek fire, Lake Michumina area; 200,000 acres burned June 12.

Birch Creek fire, Lake Michumina area; 150,000 acres burned June 13.

1926 Mile 17 Richardson Highway fire. Started by children who set a tree afire to drive out a squirrel; 38,400 acres were burned.

Chatanika River area fire; started by construction crews; area assumed to be in excess of 100,000 acres.

1927 Willow Creek fire, Copper River country. Started by construction crews. Burned between the Copper River and Tonsina River with the Richardson Highway as the western boundary. Area burned, 128,000 acres.

Columbia Creek fire, Fairbanks district. Presumably started by a rancher who set a fire to scare bears that were muddying the water hole used by his horses. Area burned, 5,000 acres.

1930 Beaver fire. Started at Beaver and burned 15 miles east and 14 miles north; area covered, 134,400 acres.

1934 Henry Martin fire. Area burned, 144,000 acres in District 3.

1935 Kvichak River fire. This fire, started about May 20, extended over about 640,000 acres.

Iliamna Lake fire. Over 1,900,000 acres burned.

1936 A fire started 10 miles east of the mouth of the Black River and burned to the head of Rat River; 288,000 acres burned.

1937 Sheenjek River burn. Started at Bootleg Bend on the Porcupine River, burned to the Sheenjek River, then northeasterly to Fortymile on the Coleen River. Believed to have been started from a smudge fire set by a rat trapper. Area burned, 312,320 acres.

1940 Box Car burn. This fire started at Eight Mile on the Porcupine River, burned to the mouth of the Sheenjek River and across to Christian River; 192,000 acres burned.

Stevens Village fire. This fire burned from Stevens Village 20 miles north and 10 miles south, averaging 10 miles in width; 192,000 acres were burned.

Ruby-Poorman fire. The area burned extended from Ruby to Poorman. It burned all summer, from June to August; 1,250,000 acres were burned.

Other large fires in 1940 included the following: Stoney River, 750,000 acres; Candle, 450,000 acres; Tanana River, 192,000 acres; and Birch Creek, 640,000 acres.

1941 Ed Berg fire. Started 25 miles up Beaver Creek and burned across to Birch Creek and then between the two streams to Fifty Mile; 216,320 acres burned.

Beaver fire. Extended from the East Fork of the Chandalar River to the Hodzana River, jumping the Hadweenzic River; 268,800 acres were burned.

Fishhook fire. Burned from Fishhook town to the Little Black River, thence down the Little Black for 10 miles and back to the Black River; 128,000 acres were burned.

Other large fires in 1941 included the following: Wood River, 252,800 acres; Porcupine River, 256,000 acres; Ruby (2 fires), 202,000 acres; Galena, 112,000 acres; Unalakleet, 1,000,000 acres; Selawik, 500,000 acres; Kobe, 136,640 acres; and Beaver Creek, 211,200 acres.

1942 Wood River fire. Burned 250,000 acres.



1943 Two fires in the Fort Yukon district burned 224,000 acres, and on the Black River 179,200 acres were burned over.

1944 Birch Creek fire. Burned 96,000 acres.

1947 Among the large fires in 1947 were the following: Salcha River, 187,000 acres; Dubli-Koyukuk, 192,000 acres; Kenai Peninsula, 421,000 acres; Tazlina, 125,000 acres.

1950 Approximately 1,800,000 acres were burned in the region east of Fort Yukon.

From the record it is clear that the forests of the Alaska interior have been subjected to extensive and repeated fires for the past several hundred years. Prior to the advent of the white man, the natives and lightning storms started fires that spread over large areas. There seems to be little basis for the view that the Indian, prior to contact with white men, was prudent in his use of fire. Fires were started intentionally by the Indians for signaling, and, to some extent, to make hunting easier. Carelessness with camp fires and smudge fires to combat mosquitoes was even more general and was certainly a major cause of forest burning.

With the advent of white men in the Territory near the end of the 19th century, fires became even more widespread than previously. Particularly affected were those districts where gold placer deposits were discovered. A map of the Fortymile Quadrangle prepared by Barnard (*9*) shows that at that time (1900) only 3.6 percent (54 of 1,481 square miles) of the forest land had been burned over. Barnard wrote, "The entire area of this quadrangle is fairly well timbered to an altitude of 3,000 feet, save some areas which have been burned over . . ." Since then most of the region has been burned.

Railroad and highway construction also led to a rash of fires, many of them among the largest the Territory has suffered.

The inroads that fire has made on the forest resources of the Alaska interior, especially since 1900, may be traced to two attitudes that are all too often encountered. The first is that fire is good for the country. This view was formally expressed in a letter written by an official of the Federal Government in 1915 (an exceptionally bad fire year), as follows:

> I have heard men who have lived in Alaska many years, who have the interest of the country at heart and who have no axe to grind, make the statement that the best thing that could happen to the Susitna and Tanana Valleys and similar locations in Alaska would be for the government to employ a force of men and at an opportune time in a dry season, burn off the whole business.
>
> In the Tanana Valley last summer there were many big forest fires and I could but notice the attitude of the different people I met remarking on it. Invariably the new-comer lamented the fact that so much timber was being destroyed. The old-timer said very little on the subject, but wore a smile of satisfaction.

The second attitude, which certainly contributes to the occurrence of forest fires, is that they do no harm because the timber is worthless anyway; it cannot be converted into cash at the present time nor in the immediate future! Fires in "brush" (often stands of young

spruce or birch) are thought by many to be no cause for concern because the "brush" has no value. These attitudes are not shared by the majority of Alaskans. They are, however, expressed with sufficient frequency to cause concern for the future of the forest resource.

The reasons advanced for intentional burning of forest lands are numerous but the most common are: (1) To increase moose feed, (2) to increase grass (chiefly *Calamagrostis canadensis*) for forage, (3) to kill mosquitoes and other insect pests, (4) to make prospecting easier, and (5) to provide dead wood for fuel. Unintentional burning occurs chiefly as a result of general carelessness with fire. Camp fires are left before they are extinguished, proper precautions are not taken when clearing land or disposing of debris along rights-of-way, and smoking materials are discarded before they are out.

There is need for an enlarged program to make the people in the Territory realize the value of the forest resource and appreciate the damage to that resource by wildfires. The attitude that fires do no harm to the forest because "nobody owns it" should be replaced by a realization that each fire reduces the wealth of the Territory and its inhabitants.

## EFFECT OF FIRE ON FORESTS

Fires destroy forest communities wholly or in part and usually result in changes in composition. Usually the stands which follow fires are composed of species different from those that previously existed on the areas concerned. This may be good or bad, depending on the utility of the stands that preceded and succeeded the fires. Climax types or communities tend to be replaced, as a result of fire, by types representing early successional stages. The new stands are usually composed of fewer species, and as a rule, species less tolerant to shade than those destroyed. The new forests tend to be essentially even-aged. Pioneer species that invade areas swept by severe fires are frequently short lived in comparison with the long-lived climax species. Another common feature of pioneer species is that light, easily disseminated seeds are produced in tremendous numbers, thereby favoring the entry into denuded tracts.

### Trees

In one respect all forest trees in the Alaska interior are similar; they are killed by severe fires. No species, with the possible exception of balsam poplar, has bark sufficiently thick to withstand the high temperatures that are generated, especial y around the basal portions of the boles. This is confirmed by the fact that living trees with fire scars are uncommon. Only rarely are such trees encountered and then almost invariably they are located at the extreme edges of burned areas where the intensity of the fire was low. Lacking also is the capacity for crowns killed by fire to regenerate from dormant buds. Further, most of the trees in the Alaska interior have very shallow root systems, which are severely damaged, if not completely destroyed, by intense fires. Ecological differences in the species occur, however, and some of them are important from the standpoint of reaction to burning.

#### *White Spruce*

White spruce is very susceptible to destruction by fire. The trees have thin, easily damaged bark and the living branches of the crown commonly extend nearly to the ground. Being very shallow rooted, white spruce is severely affected by slowly burning, hot surface fires in the deep forest floor. A severe fire will burn living roots as large as 8 to 9 inches in diameter, leaving only stubs attached to the stumps. Mounds of spruce cone scales 1 to 2 feet in depth and 10 to 12 feet in diameter around the bases of occasional trees (fig. 5) provide fuel for unusually hot and persistent local fires. These mounds represent cone caches and feeding stations of red squirrels (*Tamiasciurus hudsonicus*). The heavy growth of beard lichens (*Alectoria jubata* and *Usnea comosa* ssp. *comosa* chiefly) on the trees in some stands is probably also a factor favoring the spread of fire.

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FIGURE 5.—Accumulation of cone scales around the base of an 18-inch d. b. h. white spruce is the result of squirrel activity. The debris favors deep burning at the bases of trees.

White spruce is often at a disadvantage in seeding burned areas because it does not bear seed at as early an age as most of its associates. Furthermore, it is often present as an understory under paper birch or quaking aspen and hence is not capable of seed production. There are no data on the quantity of seed produced by white spruce in Alaska. It is presumed, however, that its seed production may be similar to that of Norway spruce in northern Europe. Borg (*16*) reported that in northern Europe a Norway spruce forest of full density occasionally produces a seed fall of about 4 million seed per

acre. Kohh (73) stated that stands in Estonia having a crown density of 60 percent produced about 3 million Norway spruce seeds per acre. Hesselman (61) placed production in good seed years at around 2 to 4 million seeds per acre. It is possible that in favorable years, such as 1951, production of white spruce seed in Alaska is at least as high as the values cited for Norway spruce. Hesselman (61) pointed out an interesting relationship between the occurrence of forest fires and heavy seed crops of Norway spruce in Sweden. He found that warm summers and abundant seed production occur together and noted that forest fires are unusually common during warm summers. Thus, during periods with warm summers, in natural forests undisturbed by man, good seed years and extensive fire years tend to occur together.

Renvall (128), studying tree seed production at high latitudes and elevations in Finland, concluded from his own studies and the work of others that the viability, total production, and the seed year recurrence interval decreases with increasing latitude or elevation. He reported that in Scotch pine stands in about latitude 69°30′ N., along the forest limit, no reproduction had started in 60 years. The periods between earlier seed years were established to have been about 90, 110, and 75 years or, in round numbers, about every 100 years. Renvall also pointed out that forest fires are a substantial evil in the far north where seed years may occur very infrequently.

Information on the distances to which white spruce seed is disseminated in Alaska is not available, but the average effective distance is probably much less than for paper birch, quaking aspen, and balsam poplar. Heikinheimo (58) suggested that Norway spruce seed may often be scattered more than 300 feet from the parent trees and pointed out the possibility of drifting much greater distances over crusted snow. Holman (62), writing of conditions in the vicinity of Lesser Slave Lake, Canada, concluded that the distance from spruce seed trees where good reproduction can be expected (seedbed conditions being favorable) is not over 4 chains (264 feet) to leeward; to windward a distance about equal to the height of the seed trees.

Although white spruce is shade tolerant, able to survive for long periods under the shade of, and in competition with, overstory vegetation, it reproduces well on bare mineral soil following fires, and makes good growth when exposed to full sunlight. Bedell (10) stated that in Manitoba white spruce reproduction does not readily establish itself on a heavy layer of litter and humus but will do so on exposed mineral soil. He quoted unpublished data of Tunstell who concluded that good white spruce reproduction occurred only on burned areas. During the present investigation no instances were seen where the ash residue inhibited germination and survival of spruce. However, Heikinheimo (58) found that ash of birch inhibited germination of Norway spruce more than it did birch and alder. His germination studies were made in soil to which varying proportions of birch ash had been added.

The occurrence of spruce seedlings on rotting logs and stumps under forest canopies has been observed repeatedly. Bedell (10) mentioned such occurrence in forest stands in Manitoba and suggested that "The presence of these seedlings on rotten logs is believed to be due to the greater amount of moisture available." Melechow (92)



observed spruce seedlings developing on rotting logs in a forest on the Dwina River in Russia. He noted that various investigators had reported this as follows: Fabricius explained the occurrence on the basis of good aeration of the root space from the side. Tschermak mentioned the stable moisture supply and favorable level of nutrient materials. Melechow suggested that the seedlings on logs are less subject to injury from freezing and abrupt temperature changes. Thus seedlings on logs are in a more favorable microclimate than those on the forest floor.

Fires are especially destructive to white spruce seed for, unlike black spruce, the cones open at maturity and the seed is disseminated. Following a fire in white spruce, regeneration of the species must generally come from seed blown in from adjacent unburned areas although some seed may be supplied from previously unopened cones that escaped destruction on the trees. Hesselman (61) said that some Norway spruce seed in the forest floor may live through a forest fire. This possibility exists also in white spruce but it is regarded as unimportant.

In many localities white spruce appears to be a hardier species than black spruce. This is contrary to the views of many writers, but agrees with the observations of Hustich (64). He pointed out that where the two species grow together white spruce always grows at higher elevations and usually attains the form of a small, if stunted, tree where black spruce only creeps on the ground, reaching approximately the height of the snow cover.

### *Black Spruce*

Black spruce, when growing on upland soils, is as susceptible, or more susceptible, to destruction by fire than white spruce. The factors which render white spruce liable to destruction apply equally to black spruce. Extensive upland areas of black spruce have been completely wiped out by fire. Even surface fires kill black spruce and burn off many of the roots, resulting in early windthrow of the snags (fig. 6). On relatively wet lowland areas the likelihood of complete destruction is much less. Here individual trees, and trees in irregular groups or stringers, are likely to survive. This is important because a continuing source of seed is thus provided for restocking. Many, if not most, of the seedlings of black spruce on burned-over areas originate from seeds present in unopened cones persisting on the trees at the time of the fire.

Seed production in the species appears to be earlier and more regular than in white spruce; total failures in seed crops seem to be infrequent. Gilmore (48) in 1925 discussed conditions in Newfoundland. He mentioned black spruce saplings bearing seed when 14 years of age. LeBarron (78) in Minnesota observed that there is substantially less fluctuation in annual seed fall than in annual seed production. Under normal conditions not all the seeds are shed from black spruce cones for 2 to 3 years following maturity. As a result, black spruce trees, at any given time, usually retain considerable amounts of viable seed. This supply, stored on the trees near their tops, is seldom completely consumed even in severe crown fires. The

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FIGURE 6.—Windthrown black spruce, 3 years after a surface fire that killed the trees and burned off many of the roots. Fire hazard will be high for many years. Kenai Peninsula, 1950.

outer portions of the cone scales may be charred but the seed remains viable and, in large measure, accounts for the abundant regeneration that usually develops. The behavior of black spruce following fires is analogous to that of certain other "fire species," notably jack pine, lodgepole pine, and pitch pine.

Red squirrels devour great quantities of black spruce seed, clipping off small branches with clusters of cones from the upper crown of trees. This practice is responsible for the pruned stem segments so characteristic of black spruce crowns. LeBarron (*78*) noted this influence and mentioned the resulting bunchy appearance of black spruce tops in Minnesota. The activity of red squirrels in black spruce forests is further indicated by the occurrence of large mounds of cone scales where cones have been cached and the seeds eaten.

Black spruce, like white spruce, is relatively tolerant of shade and competition from other vegetation. However, regeneration is most abundant and seedling growth is most rapid on mineral soil receiving full, or nearly full, sunlight. Under forest conditions black spruce regenerates regularly by layering of basal branches, producing a groupwise distribution pattern, seen most dramatically from the air.

An interesting habit of black spruce (and perhaps also white spruce) was described by Capps (*28*). On the north bank of the White River, about 8 miles below Russell Glacier, is a bluff on which are growing spruce trees with storied root systems. Capps (*28*) explained that spruce seedlings first develop shallow, flat root systems on becoming established in the moss-covered organic matter that overlies the mineral soil. As the moss cover increases in thickness, the level of permafrost rises and causes the trees to develop new and higher sets of roots. Trees with several sets of roots may be seen. This feature also has been described by LeBarron (*77*) in the Lake States. He regarded the eventual replacement of old roots by new as a response to better aeration near the surface of the soil.

## *Paper Birch*

Alaska paper birch appears to be the most common tree birch in the interior of Alaska. On the Kenai Peninsula, Kenai paper birch is the principal species. In view of the fact that the former variety is by far the most widespread in its occurrence and that ecological differences between varieties are not perceptible, no further distinction will be made. Young birch is readily killed by fire because of the relatively thin bark. In later life the bark becomes thicker but it is then also more flammable as it begins to exfoliate. The tinderlike quality of birch bark is well known. However, more birch trees survive in burned-over areas than is the case with white spruce. The principal reason is that the forest floor under birch trees and in birch stands is not as deep as under white spruce, so that surface fires generate less heat and are less persistent.

Regeneration by sprouting from root collars of fire-killed birches is frequent in young stands, but less frequent in middle-aged and old stands. The sprouts arise from dormant buds around the base of the stump and contribute to restocking. Regeneration from this source is not, however, as important as seedling reproduction.

Birches produce seed at an early age; Heikinheimo (*58*), in Finland, reported seed produced by birch sprouts 10 years of age. Kohh (*73*) investigated seed production in *Betula verrucosa* and *B. pubescens* in Estonia and stated that in a good seed year a 70-year-old stand on site I produced from 110 to 244 million seeds per acre (average 200 million). In his studies of *Betula alba* in Finland, Kujala (*74*) reported that trees burned sufficiently to kill the cambium completely around the base still retained a mantle of foliage and yielded an excess of ripe seed except on the lowest branches. If this habit is general in birch it must have an important influence on reproduction following fires.

Birch seed is light and readily disseminated by the wind; thus the species is a rather highly mobile pioneer. Mineral soil seedbeds and full sunlight provide favorable conditions for initial establishment and subsequent rapid growth (fig. 7). Splendid dense stands of well-formed trees frequently follow fires if adequate supplies of seed are available.

## *Quaking Aspen*

Quaking aspen is killed by hot fires but in pure stands the fires are characteristically light. Conditions for decomposition of litter under aspen stands are relatively favorable; the leaves are not particularly resistant to decay, and stand density is generally low enough to permit adequate precipitation and sunlight to reach the ground. As a result, the accumulation of forest floor material is usually too light to carry a hot, persistent fire.

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FIGURE 7.—Dense growth of Alaska paper birch seedlings on mineral soil in the Goose Bay-Knik area.

After the great burn of 1947 on the Kenai Peninsula, green stands of aspen frequently remained, surrounded by areas in which the spruce was completely killed (fig. 8). This does not mean that aspen stands are immune to damage by fire. Surface fires do pass through the stands and trees are killed but seldom is destruction as complete as in spruce or birch. Stump sprouts from fire-killed aspen are uncommon but root suckers are extremely abundant. Areas that supported aspen prior to a fire are almost certain to be regenerated with the same species as a result of root suckers alone. Reproduction is striking in tracts where a severe fire has swept through a spruce forest with occasional aspen trees. Around the base of each dead aspen tree, root suckers arise abundantly, covering roughly circular areas whose diameters depend on the size and root spread of the killed tree.

In the Lake States it was found that burning in uncut stands of aspen stimulated height growth of aspen root suckers (*160*). In the first year after burning the average height of root suckers on burned areas was 2.43 feet, on unburned areas 1.97 feet.

Seedling reproduction of aspen is also common. Seeds are borne in tremendous numbers and they are admirably adapted for widespread dissemination by wind. Kittredge and Gevorkiantz (*71*) indicate that there are 2.5 to 3 million aspen seeds per pound. Reim (*127*) calculated that in northern Europe during good seed years aspen stands produce 162 to 202.4 million seeds per acre (excluding those destroyed by insects). A single good tree may produce about 54 million seeds. Quaking aspen is a pioneer species. It is intolerant of shade, characteristically develops in even-aged stands, and finds mineral soil exposed to full sunlight favorable for establishment and subsequent development.

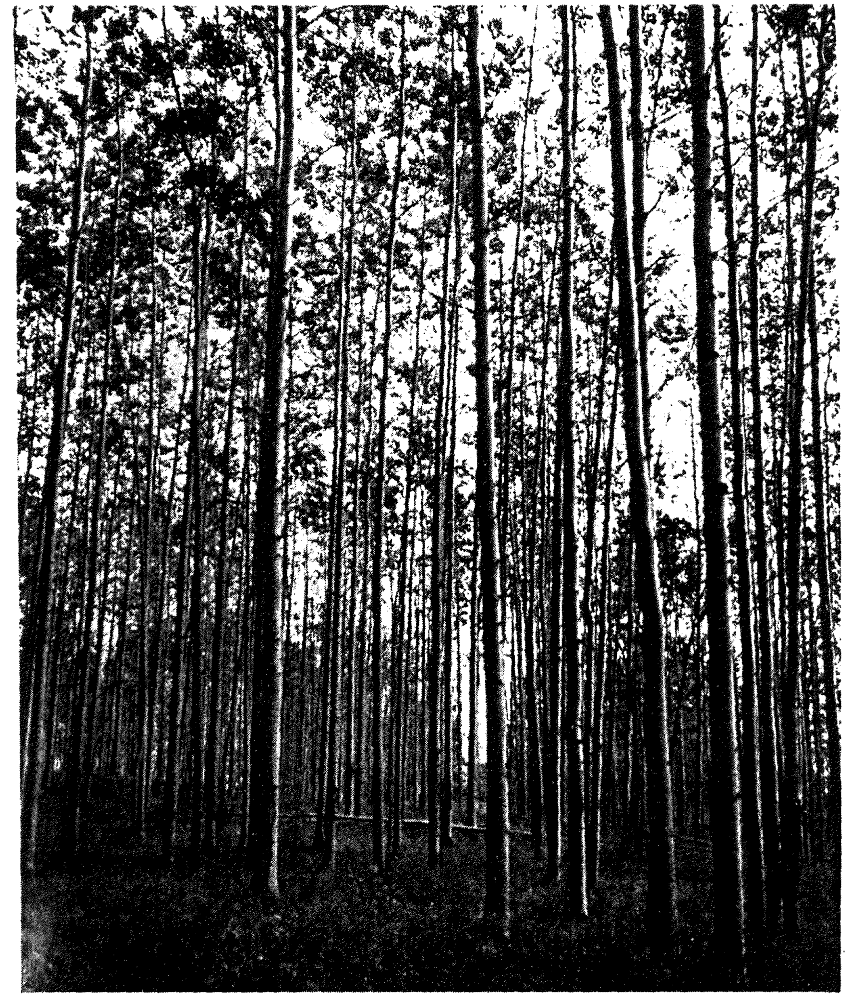

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FIGURE 8.—A 65-year-old quaking aspen stand. The dominants are 6 to 11 inches d. b. h. and 65 feet tall. A light surface fire killed all understory white spruce in 1947. Kenai Peninsula, 1950.

### *Balsam Poplar*

Balsam poplar is probably more resistant to destruction by fire than any other forest tree in the interior of Alaska. Bark thickness, near the base of the bole, is often 4 or more inches on mature trees. As in aspen stands, surface fires in the balsam poplar type tend to be light because of the relatively thin accumulation of forest-floor material.

Regeneration by root suckers is common in balsam poplar stands through which fire has passed. Seedling reproduction is also abund-

ant whenever mineral soil has been exposed and a source of seed is at hand. Like aspen, balsam poplar is intolerant to shade and produces tremendous quantities of seeds that are easily and widely disseminated by wind.

The species is normally regarded as a pioneer tree on recently deposited alluvium along streams and river valleys subject to overflow. It is also present on upland areas where, as a result of fire, exposed mineral soil has provided an opportunity for the seeds to germinate. In fact, occurrence of balsam poplar in anything approaching pure stands on upland areas is practically contingent on the occurrence of fires.

## Subordinate Forest Vegetation

### *Shrubs*

Shrubs, because of their low stature and small stems, are especially liable to destruction by fire. As a group, however, they have a rather remarkable capacity for vegetative regeneration through sprouts arising from stem bases and roots. Much of the reproduction following fires is vegetative. The establishment of shrubs with fleshy or pulpy fruits is relatively slow on burns because these plants are dependent on animals for seed dispersal (*74, 117*). Animals are not abundant on burned areas, at least for several years after the fire. On the other hand, the willows, which form the largest single group of shrubs in Alaska, produce minute hairy seeds admirably adapted for wind dissemination. Furthermore, they produce seed at a very early age; sprouts 2 to 3 years of age bear catkins. Therefore, the willows are usually well represented in the seedling regeneration of burned areas. Brief notes concerning the ecology of certain species follow:

*Arctostaphylos uva-ursi* reproduces following fires from protected seeds in the forest floor, as does *Empetrum nigrum* (*134*). *A. uva-ursi* reproduces more regularly than *E. nigrum*, presumably because of better germination of the seed. Kujala (*74*) included *Arctostaphylos* in the group of plants incapable of vegetative reproduction from underground parts; in his opinion it reproduces mostly around the edges of spots where burning was deep, to mineral soil.

*Empetrum nigrum* reproduces from seeds that are buried in the forest floor, thus escaping damage by fire (*134*). Germination is slow and erratic, with the result that the seedlings come in gradually over a period of 3 to 5 years. Aaltonen (*2*) regards *E. nigrum* as a species that is very susceptible to fire damage and spreads only slowly. To him it appeared that at least 20 to 30 years were required after a fire for *E. nigrum* to regain normal density.

Following fires, *Ledum palustre* regenerates from rootstocks, according to Sarvas (*134*). Kujala (*74*) also listed it with species possessing underground reproductive organs. Townsend (*156*) quoted from George Cartwright's Labrador Journal, published in 1792, to the effect that when old spruce forests were burned, Indian-tea [*Ledum groenlandicum*] was generally the first species to reappear.

*Vaccinium uliginosum* reproduces after fires from protected rootstocks (*134*).

*Vaccinium vitis-idaea* also reproduces from rootstocks (*2, 74, 134*).

### *Herbaceous Plants*

It is impossible to generalize on the effects of fire on herbaceous plants because they differ so greatly in life form, seed habits, and other ecological characteristics. Regeneration in many instances is vegetative, particularly in those species that appear earliest after fires. Reproduction by seed is, however, more general and more important. Many, if not most, of the species that invade burned areas are those whose seed is easily disseminated by wind. In studies of burned areas on two islands in the archipelago east of Helsinki, Pettersson (*117*) noted that "the anemochores are represented in a manifest multitude." Vogler (*162*) investigated the alpine plants in Switzerland and concluded that the younger a vegetation community the greater the percentage of plants whose seed is wind disseminated. On recently burned areas the scarcity of plants with fleshy fruits, noted by Kujala (*74*), is explained by Pettersson (*117*) as resulting from the fact that animals are not attracted to burned areas. Plant species that produce large quantities of easily disseminated seed at an early age have an advantage over those not possessing these characteristics. Seed supply is an important consideration in the revegetation of burned areas. Failure to evaluate the quantity of seed produced, its adaptations for dispersal, and the efficiency of the agents of dispersal often leads to erroneous conclusions on the significance of site factors. Absence of a species in a given area or at a given spot is not direct evidence that the habitat is unfavorable.

Species invading recently burned areas tend to be those which develop best in full light. Often they are characterized by very rapid growth.

Germination of seed and survival of seedlings is highest in areas or spots where mineral soil has been exposed. On the other hand, species that reproduce vegetatively from underground parts tend to come in best on areas where the fire burned less intensely. These differences in species, together with the heterogeneity of the pattern of burning—often more intense burning under spruce trees than in the intervening space between spruce trees—result in a mosaic of vegetation. This mosaic is evident, on a grand scale, in the pattern of broad forest types and it is also evident, on a minor scale, in the occurrence of species and group societies of the subordinate vegetation. Brief notes as to the ecology of certain herbaceous plants follow:

*Calamagrostis canadensis* is widely recognized as a species that develops abundantly in burned areas. Establishment of *Calamagrostis* following forest fires has been reported frequently, especially by explorers or hunters who employed pack animals.

*Festuca ovina* reproduces after fires from basal buds as well as from seed (*134*).

*Epilobium angustifolium*, the common fireweed of the north, has been referred to by Graff (*51*) as a pyrophilous plant. It grows in great numbers on practically all burned areas in the interior of Alaska (fig. 9). Skutch (*146*) quoted an old observation by Irmisch, "The primary as well as the secondary roots of the young seedlings develop buds freely, which sometimes give rise to plants in the succeeding year. The shoots from old roots may grow so fast that they bloom within a month. The roots are undoubtedly capable of persisting for several years in a dormant condition until the environment changes by clearing or burning the woods." Summerhayes and Williams (*149*) noted that the species has extensive roots usually capable of producing adventitious aerial shoots. In addition to this remarkable capacity for vegetative reproduction, *Epilobium angustifolium* produces an abundance of seeds which are easily and widely disseminated by wind. The species is regarded, by Hesselman (*59*) and others, as a nitrate plant, indicating active nitrification in the soil of burned areas. Sarvas (*134*) noted that reproduction is particularly abundant on spots that have been burned deeply, exposing mineral soil.

*Linnaea borealis* is completely destroyed by fire, according to Sarvas (*134*). Here and there unburned spots serve as centers from which the plants spread.

*Lycopodium complanatum* has underground stems and reproduces from these after fires (*74, 134*). *L. annotinum* has shallower underground stems; consequently it is less frequently encountered where burning has been deep.

Species of *Pyrola* are included by Kujala (*74*) in the group of plants that are able to reproduce from underground parts.

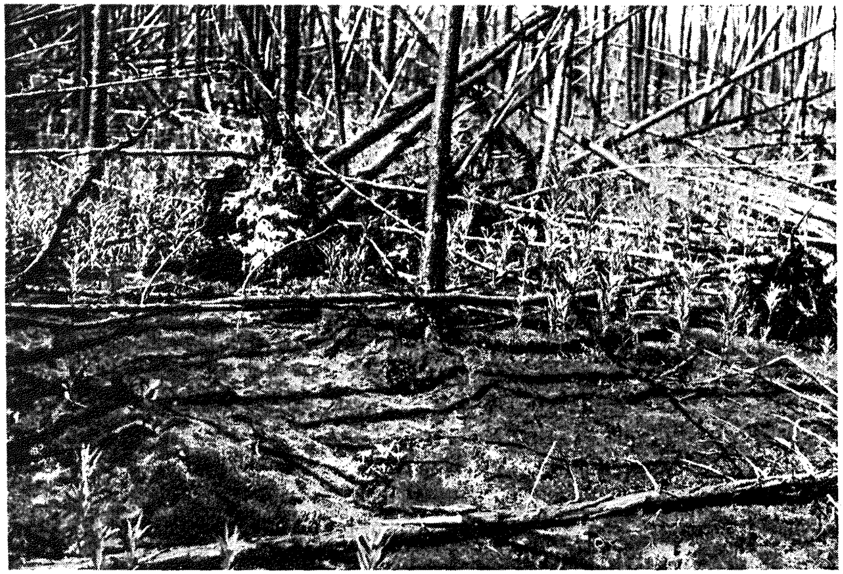

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FIGURE 9.—A 110-year-old stand of black spruce 3 years after a fire. The vegetation is largely fireweed (*Epilobium angustifolium*). Kenai Peninsula, 1950.

**Mosses** occur abundantly in the forests of interior Alaska. They form a characteristic stratum in nearly every stand and must be regarded as an integral part of the forest communities. Persson (*114*) calculated that 85.5 percent of the 592 species of bryophytes known in the Alaska-Yukon region are also found in Europe. Their importance is due principally to the fact that they influence soil temperature (and hence the position of the permafrost), soil moisture relations, seedbed conditions, soil erosion, and hydrologic relations. The usefulness of mosses to wildlife is very limited (*91*). Capsules are reported to be eaten by the spruce grouse (*Canachites canadensis*) and by mice and lemmings; the plants are used by some birds and mammals in nest building.

Mosses reproduce by spores, but probably most of the regeneration after forest fires is vegetative. Brief notes concerning the reaction of certain moss species to fires follow:

*Ceratodon purpureus* is a fire species in the sense that it comes in very abundantly after fires. Summerhayes and Williams (*149*) reported the appearance of *Ceratodon* in quantity 3 years after felling and burning in a pine forest in England. Skutch (*146*) found it an abundant species 4 years after a fire on Mt. Desert Island, Maine. Sarvas (*134*) noted that it reproduces by rhizoids on burns. It also reproduces by spores at an early age and may through them grow a complete cover in as little as 5 years.

*Dicranum bergeri*, *D. fuscescens*, and *D. majus* reproduce vegetatively after fires, according to Sarvas (*134*), but do not attain great importance on burned areas.

*Pleurozium schreberi* is almost completely killed by fires, but usually some parts capable of reproducing remain. Sarvas (*134*) stated that soil conditions on burns are such, however, that these remnants usually do not regenerate. Only after 30 to 40 years when a closed forest stand has developed does the species begin to assume its previous importance.



*Pohlia nutans* is said by Sarvas (*134*) to regenerate by rhizoids after fires and to produce spores in about 5 to 10 years.

*Polytrichum commune* enters burned areas early and may replace species such as *Ceratodon purpureus*. Skutch (*146*) reported *P. commune* as locally abundant in moist spots in a burn in Maine one year after a fire. Four years after the fire it had spread over considerable areas, replacing the liverwort *Marchantia polymorpha*. Comparable replacement of *Marchantia* by *Polytrichum* was noted in England by Summerhayes and Williams (*149*).

*Polytrichum juniperinum* and *P. piliferum* have deeply penetrating rhizoids, which, following fires, serve to reproduce the species (*74*, *134*). Sarvas stated that species of *Polytrichum* are most characteristic on areas 10 to 20 years after a fire; they suppress the earlier appearing species of *Ceratodon* and *Pohlia* and, in turn, are themselves later suppressed by other mosses and lichens. Aaltonen (*2*), Skutch (*146*), and Hustich (*65*) all regarded these species of *Polytrichum* as pioneers on burned areas.

*Marchantia polymorpha* is a liverwort but for convenience it is mentioned at this point. It is so common on deeply burned areas that Graff (*52*) referred to its pyrophilous character and Sarvas (*134*) referred to it as the classical forest fire liverwort. *M. polymorpha* enters burned areas where mineral soil has been exposed, appearing within 1 to 2 years after the fire. The early entry of the species and its rapid and extensive spread have been noted by Summerhayes and Williams (*149*) and Benson and Blackwell (*15*) in England, by Skutch (*146*) in Maine, by Graff (*51*) in the Rocky Mountain region, by Torrey (*154*, *155*) in New Jersey and Virginia, and by others. It is succeeded, within a few years, by mosses and peltigeras.

**Lichens** form a large group of plants, a number of which are highly important as food for caribou (*Rangifer arcticus*) and reindeer (*Rangifer tarandus*). Lichens are usually destroyed whenever a surface fire sweeps over an area. The general situation has been stated by Lynge (*84*), a close student of the group, as follows:

> If a lichen vegetation has been disturbed or driven away from its natural habitat it will in many cases require a long time before it again can cover it. This is best seen after forest fires. I have seen gaps made by old forest fire, 50 years or more old, where the range of the fire could be traced on the lichen vegetation, *Cladonia alpestris* was more scarce and less developed there than outside the range of the fire. Even quite small fire gaps require an extremely long time before they will be covered with the same lichens again. I have seen experimental fields, 1 square meter large in fine *Cladonia* fields where no trace of *Cladonia alpestris* was visible 5 to 6 years after the fire, and Lapponian tent fire-places so old that even their surrounding stones were sunk into the earth where the place was recognizable on the vegetation. The original lichen cover was gone, sometimes replaced by mosses or by other lichens, as *Peltigera spuria* and *P. aphthosa*, even if the nearest station for these plants was far distant.

Kujala (*74*) expressed the view that fire has a more destructive effect on lichens and mosses than on the vascular plants.

Reproduction in lichens may be either sexual or asexual. However, production of soredia and fragmentation appear to be the most common means of reproduction. According to Perez-Llano (*113*) a considerable number of foliose lichens, as well as a few crustose and fruticose species, seldom produce apothecia and spores. Those species which appear earliest on burned areas are generally of low

stature and probably regenerate from subterranean parts and bits of unburned thallus. The taller fruticose lichens in the reindeer lichen group are likely to be exterminated by fire, and their return is generally slow.

Hustich (*65*) stated that in the lichen woodlands of northeastern Canada complete recovery of the lichen cover after a fire requires at least 40 years. He cited estimates from investigators in other countries as follows: Itkonen, 40 to 50 years; Manning, 50 years; Sarvas, 30 to 40 years. Aaltonen (*2*) stated that in Finland lichens were still not abundant 20 to 30 years after a forest fire. Tengwall (*152*) measured the rate of growth of the reindeer lichens and reported that the rate of development of small plants is about the same as that of large plants. Only when the lichens approach their maximum size does growth slow up. He noted that certain individual large lichens did not grow at all during the years that he carried on his observations; they had reached their maximum size of about 1.8 to 2.6 inches (45 to 65 mm.).

The ecology of lichens, particularly as it relates to the effects of fire, is not well understood. Considerable information has been obtained by investigators in northern Europe, however, and an attempt has been made to summarize this for certain species.

*Alectoria jubata* and other beard lichens which hang in masses from the branches of trees are readily flammable when dry; they undoubtedly contribute to the spread of fire.

*Cetraria islandica* is a heliophilous species, especially abundant in dry situations (*84*). It is destroyed by fires and occurs almost exclusively in unburned areas (*134*). *C. islandica* grows more rapidly than *Cladonia alpestris* (*84*).

*Cetraria nivalis*, usually associated with *C. cucullata* was regarded by Lynge (*84*) as growing more rapidly than *Cladonia alpestris*.

*Cladonia alpestris* is the reindeer lichen of the Scandinavian countries and grows very slowly (*84*). Sarvas (*134*) reported that 10 years after a fire numerous small plants may be encountered but that they attain full growth only after 30 to 40 years. Tengwall (*152*) calculated that 30 to 35 years were required for plants to develop to maximum size. Lynge (*84*) reported that the length of time for recovery estimated by farmers and Laplanders in Norway varies from 10 to 40 years. He remarked, "We do not know the time for full development but it is hardly possible to mention a lower figure than 25–30 years under favorable circumstances."

*Cladonia bellidiflora*, according to Sarvas (*134*), attains greatest abundance 20 to 30 years after fires; it regenerates after fire from underground parts and unburned bits of thallus.

*Cladonia cariosa*, according to Sarvas (*134*), attains greatest abundance 20 to 30 years after fires. Regeneration following fires is similar to that in *C. bellidiflora*.

*Cladonia coccifera* is generally one of the first lichens to appear on burned areas (*2*). Lynge (*84*) regarded it as a rapid grower, having seen podetia nearly 0.6 inch (15 mm.) with a small corona of red apothecia in plants not over 3 years old. Sarvas (*134*) reported that it attains greatest abundance 20 to 30 years after fires. Regeneration is similar to that in *C. bellidiflora*.

*Cladonia cornuta*, taller than *C. coccifera*, *C. cariosa*, and *C. bellidiflora*, is regarded by Sarvas (*134*) as more likely to be exterminated by fire. Aaltonen (*2*) stated that it is one of the first lichens to appear on burned areas but Lynge (*84*) regarded it as a forest lichen.

*Cladonia crispata* was considered by Lynge (*84*) as chiefly a forest lichen.

*Cladonia deformis* was reported by Aaltonen (*2*) to be one of the first lichens to appear on burned areas. Sarvas (*134*) found that greatest abundance was attained 20 to 30 years after a fire. Regeneration is similar to that in *C. bellidiflora*.

*Cladonia degenerans* attains its greatest abundance some 20 to 30 years after fires (*134*). Regeneration is similar to that in *C. bellidiflora*.

*Cladonia furcata* var. *racemosa* is taller than *C. coccifera*, *C. cariosa*, *C. deformis*, *C. degenerans*, and *C. bellidiflora*. Fire is more likely to exterminate *C. furcata* than the shorter species of *Cladonia* (*134*).

*Cladonia gracilis* was found by Aaltonen (*2*) to be one of the first lichens appearing on burned areas. Lynge (*84*) viewed it as primarily a forest plant.

*Cladonia rangiferina*, one of the reindeer lichens, is readily destroyed by fire. Sarvas (*134*) reported that 10 years after a fire numerous small plants may be found but that they attain full growth only after 30 to 40 years. Tengwall (*152*) calculated that 15 to 20 years were required for development to maximum size. Lynge (*84*) pointed out that the species has rather high light requirements.

*Cladonia sylvatica* is also a reindeer lichen. Some authors have interpreted *C. sylvatica* broadly, evidently including much material that could be referred to *C. mitis*. Sarvas (*134*) noted that 10 years after a forest fire numerous small plants may be present but that they attain full growth only after 30 to 40 years. Tengwall (*152*) calculated that the maximum size was attained in 20 to 30 years. Lynge (*84*) suggested that regeneration of *C. sylvatica* is easier than for *C. alpestris* because it reappears more quickly after great forest fires. As in the case of *C. alpestris*, Lynge wrote, "We do not know the time required for full development but it is hardly possible to mention a lower figure than 25–30 years under favorable circumstances."

Hustich (*65*), in discussing conditions in Labrador, regarded *Cladonia mitis* as the first reindeer lichen species to invade burned lichen forest. He reported that near the coast of James Bay, *C. mitis* was only 1 inch high in a prime dwarf-shrub forest that had been burned 25 years previously. It appeared to Hustich that *C. mitis* has slightly broader ecological amplitude than the other reindeer lichens, often penetrating into dry tussocks on bogs.

*Cladonia uncialis* is one of the reindeer lichens, according to Sarvas (*134*). He stated that 10 years after a forest fire numerous small plants appear but that they are not full grown until 30 to 40 years after the fire.

*Cladonia verticillata* attains greatest abundance 20 to 30 years after a fire (*134*). Following fires this species may regenerate from underground parts or unburned bits of thallus.

*Icmadophila ericetorum* tends to be concentrated on organic substrata—decaying wood and balls of humus material bared by forest fires (*134*).

*Nephroma arcticum* reaches its best development in the forest (*84*). Sarvas (*134*) regarded it as comparable to peltigeras from the standpoint of occurrence and reproduction following fires.

*Peltigera aphthosa* can endure more shade than most other lichens (*84*). Sarvas (*134*) pointed out that the habit of growth (over the moss and lichen cover) renders this plant liable to destruction by fires. In burned areas it occurs on the most lightly burned spots or areas missed by fire and from these spreads out rather rapidly.

*Stereocaulon paschale* requires about 15 years to attain maximum size (*152*). Lynge (*84*) referred to it as fast growing; it can produce full-grown thalli in 5 to 6 years. Sarvas (*134*) noted that *S. paschale* and *S. tomentosum* grow close to the ground. The relatively strong principal axis is partly embedded in the soil and after forest fires this may remain undamaged, thus serving for reproduction.

## Succession After Fire

Forest vegetation development following fires in the interior of Alaska is neither a completely fortuitous, random process nor is it an invariable, highly orderly process closely directed by a mysterious, beneficent "Nature." Elements of the fortuitous do exist but there are also elements of order. In this respect, conditions in the forests of the Alaska interior are not fundamentally different from those in the forests of regions to the south. The writer does not accept the view that ecological principles that apply in the temperate zone are not applicable in the forests of the North. The colloquial dictum that "Alaska is different" need not cause the forest ecologist to discard his working tools developed in lower latitudes.

In this study it was convenient to employ the concept of climax vegetation in the sense of self-perpetuating, terminal plant communities of considerable stability. Two categories of climax vegetation are distinguished—climatic and physiographic. The climatic climax forest is regarded as the terminal stage of successional development on moderately well-drained uplands and the physiographic climax forest is regarded as the terminal stage on poorly drained, relatively cold areas. From the standpoint of stability there is little difference between a climatic climax and a physiographic climax—for practical purposes, both may be regarded as self-perpetuating, terminal communities. There is no implication that climax forests are desirable and that subclimax forests are undesirable. Utility must usually determine the vegetation type most desired; in some circumstances this type will represent an early or intermediate stage of succession and in other instances it will represent the terminal stage, here called the climax.

In the following pages the plant communities encountered in the forested regions of the Alaska interior will be described and the course of succession indicated.

As an aid to understanding the succession leading to climax forest communities and the retrogression that follows repeated fires in the various forest types, a schematic representation is shown in figure 10. This figure represents a generalization of the course of events observed in the field. Aberrant successional stages and retrogressive changes may occur.

### *Recently Burned Areas, Currently Regenerating*

Some areas were burned so recently that they could not be assigned to specific forest types or plant communities. They are in a stage of very rapid change, with the site only partially occupied and with new plants entering each year. These burns usually were less than 10 years old.

The two most important conditions that influence development of seedlings in recently burned areas appear to be (1) the presence of viable seed, and (2) exposed mineral soil. As mentioned earlier, many of the pioneer species produce abundant seed that is readily disseminated by wind. The exposure of mineral soil is important from the standpoint of seed germination and seedling survival and growth.

Mineral soil provides a more favorable seedbed than charred organic matter because the former has (1) a more stable moisture supply, (2) somewhat lower surface temperatures, and (3) a greater supply of readily available plant nutrients. The great importance of mineral soil seedbeds for seedling establishment was observed repeatedly. In the area swept by the great fire on the Kenai Peninsula in 1947 the majority of seedlings developed where the fire had burned deeply, exposing mineral soil. Seedlings of all species were scarce in situations where the forest floor material was not appreciably reduced by the fire and the surface only charred.

The extent to which mineral soil is exposed by fire will, of course, vary with time and place. In the recently burned spruce areas examined in the course of this investigation, the proportion of mineral soil surface exposed averaged about 35 percent but varied from about

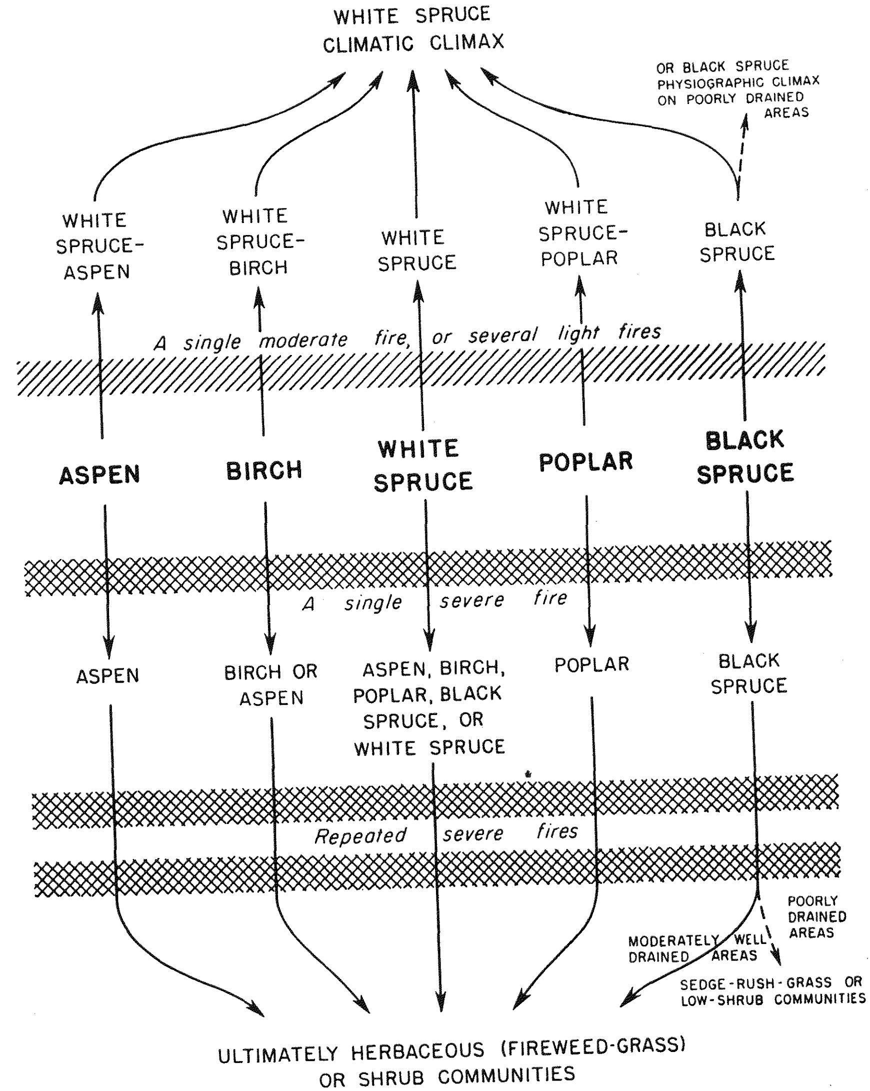


FIGURE 10.—Changes in forest types following fire.

5 to 100 percent. Burning tended to be more intense on ridges than in valley situations, and slopes with south or west exposures commonly had more mineral soil exposed after a fire than did slopes with north or east exposures. Fires are often unusually severe on rocky slopes or ridges.

More noticeable than any influence of topography or exposure, however, was the effect of the trees themselves on the pattern of burning in the forest floor. This influence has been mentioned by Kujala (*74*) in his investigations of the effects of forest fires in Finland.

He stated (*74, p. 35*) that burning was more intense under the trees than in the spaces between them. In the current study it was repeatedly observed that, in practically all fires, burning was deepest and most intense under trees; the periphery of a given deeply burned area approximately coincided with the crown projection of the tree concerned. This may be due to the following: First, and probably most important, is the fact that spruce trees have long, if narrow, crowns which must intercept much of the precipitation which falls in light rains or in light snow storms. The driest places in a spruce forest must be immediately beneath the tree crowns. A second factor, which is less important but significant, is the accumulation of cone scales frequently seen around the bases of spruce trees in stands of seed-bearing age (fig. 5).

In paper birch, quaking aspen, and balsam poplar stands burning is usually less intense than in spruce and consequently less mineral soil is exposed.

Density of vegetation on recent burns increases with the passage of time. The species that enter earliest spread vegetatively and by seed and are supplemented by later entrants.

Spruce, paper birch, quaking aspen, and balsam poplar reproduction appears in burned areas within one year after a fire. On 21 areas examined, the average number of spruce, paper birch, and *Populus* species (quaking aspen and balsam poplar) seedlings and sprouts per acre was 2,000, 8,000, and 5,000, respectively. Stocking with spruce ranged from none to 12,000 seedlings per acre; 25 percent of the plots contained no seedlings. In paper birch, stocking ranged from none to 131,000 per acre; 30 percent of the plots bore no seedlings or sprouts of the species. *Populus* seedlings and sprouts ranged from 500 to 18,000 per acre and were absent on only 5 percent of the plots. These areas had been burned from 1 to 10 years previously. With an average of 15,000 tree seedlings per acre already present and with the process of regeneration continuing, new forest stands will follow those destroyed. This conclusion is substantiated by the fact that in the interior of Alaska there are practically no barren areas resulting from single burns.

Vegetative reproduction following fires is lacking in the spruces, occasional in young and middle-aged paper birch, but very abundant in quaking aspen and balsam poplar (fig. 11). A series of milacre plots were examined along a transect 165 feet in length, arranged so that it sampled the reproduction established under a fire-killed aspen 13.1 inches in diameter. Three years had elapsed since the fire occurred. The total number of seedlings and root suckers was 59,350 per acre, of which 36,230 were root suckers and 23,120 seedlings. All root suckers exceeded a height of 1 foot and 9 percent of them had attained a height of 2.5 to 6.0 feet. The most heavily stocked milacre supported 80 root suckers and 54 seedlings, the equivalent of 134,000 stems per acre (fig. 12).

The spruces concerned are the white spruce, Porsild spruce, and black spruce. Tree birches are principally Alaska paper birch and Kenai paper birch. Of the poplars, quaking aspen is by far the most abundant, being present on nearly all plots. Balsam poplar is the common cottonwood of the interior; black cottonwood is a coastal

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FIGURE 11.—A 110-year-old stand of black spruce with occasional quaking aspen, burned in 1947. Note abundant growth of aspen root suckers around fire-killed aspen tree. Kenai Peninsula, 1950.

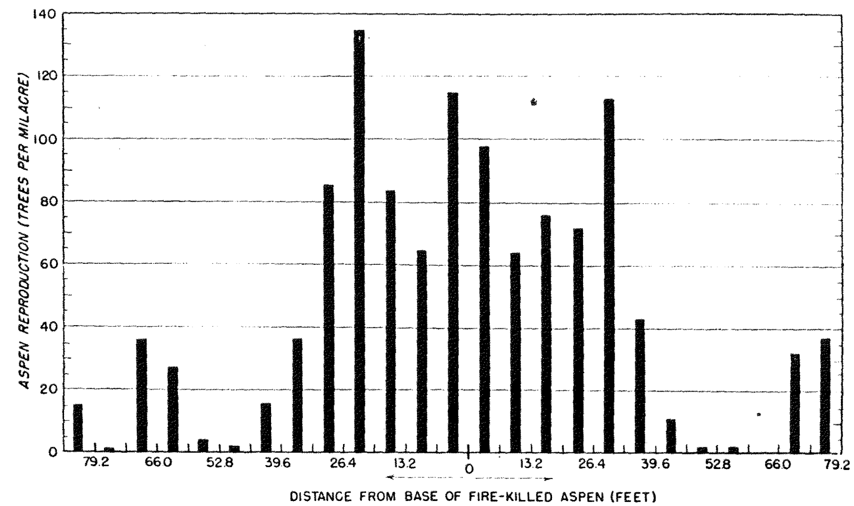


FIGURE 12.—Aspen reproduction around a 13.1-inch fire-killed aspen. Based on a transect 3 years after the fire. Kenai Peninsula.

species of limited occurrence on the Kenai Peninsula, and perhaps in the lower Susitna River valley, but is unknown throughout the interior proper.

Shrub reproduction consists predominantly of willows which, in their early years, are practically impossible to identify. Those

represented most abundantly in unburned areas adjacent to recent burns were Bebb willow, Scouler willow, littletree willow, and Barclay willow. Stocking with willow reproduction averaged, for all plots, 5,700 seedlings and sprouts per acre, the numbers ranging from none to 53,000. Willow reproduction was lacking on 25 percent of the plots. Sprouting from fire-killed young willows is abundant but old suppressed willows produce few sprouts. Of the other shrubs, *Cornus canadensis*, *Rosa acicularis*, and *Vaccinium vitis-idaea* are the most abundant, being found on nearly all recently burned areas. Occasional are *Ledum palustre* ssp. *decumbens*, *L. palustre* ssp. *groenlandicum*, and *Vaccinium cespitosum*.

SHRUBS, RARE

*Alnus sinuata*
*A. tenuifolia*
*Arctostaphylos alpina* ssp. *rubra*
*A. uva-ursi*
*Empetrum nigrum*
*Potentilla fruticosa*
*Ribes triste*
*Shepherdia canadensis*
*Vaccinium uliginosum*

Reproduction of shrubs other than willows in recent burns is for the most part vegetative, with some seedlings developing from seed stored in the forest floor.

Grasses enter recent burns promptly, usually appearing within 1 to 2 years after a fire. Three species, *Agrostis scabra*, *Calamagrostis canadensis*, and *Festuca altaica*, predominate on areas recently burned. These species have a relatively high frequency of occurrence, but the density of their cover is low, generally less than 10 percent. Other species occasionally encountered, and entering after the third or fourth year following the fire, are *Arctagrostis latifolia*, *Calamagrostis purpurascens*, and *Poa pratensis*.

Grasslike plants appear in sparse number 3 to 4 years following fires. *Carex concinna*, *C. media*, *C. rossii*, and *Juncus castaneus* are present.

A number of species of forbs are represented. *Epilobium angustifolium* is the most abundant plant, often attaining densities of cover of as much as 50 percent. It is present in practically every area that has been recently swept by fire. Species of *Lupinus*, chiefly *L. polyphyllus*, are likewise abundant but density of cover usually is not more than 5 percent. *Linnaea borealis* var. *americana* is widely distributed but densities are usually very low. *Polemonium caeruleum* ssp. *villosum* and *Pyrola secunda* are common.

FORBS, OCCASIONAL TO RARE

*Achillea borealis*
*Aster sibericus*
*Astragalus alpinus*
*Comandra livida*
*Corydalis sempervirens*
*Descurainia sophioides*
*Epilobium adenocaulon*
*Equisetum arvense*
*E. pratense*
*E. scirpoides*
*Erigeron acris* var. *asteroides*
*Galium boreale*
*Gentiana propinqua*
*Hedysarum alpinum* ssp. *americanum*
*Lupinus arcticus*
*Mertensia paniculata*
*Oxytropis campestris* var. *varians*
*Pedicularis labradorica*
*Primula cuneifolia* ssp. *saxifragifolia*
*Pyrola asarifolia* var. *incarnata*
*Silene williamsii*
*Solidago oreophila*
*Stellaria longipes*
*Tofieldia coccinea*
*Trientalis europaea* ssp. *arctica*

During the first 10 years no noteworthy changes were observed in the forb cover other than a gradual increase in the number of species represented and in density of cover.

Mosses are limited to a few species that become common to abundant on recently burned areas 3 to 4 years after a fire. *Ceratodon purpureus* is a fire species appearing 2 to 3 years after fires and spreading rapidly. Often it attains a density of cover approaching 100 percent on deeply burned areas where mineral soil has been exposed. *Polytrichum commune* (and to a lesser extent *P. juniperinum*) enter with *Ceratodon*. The liverwort *Marchantia polymorpha* is also a fire species, entering burned areas within the first 2 years following a fire; locally it may attain a density of cover approaching 100 percent. These mosses and the liverwort are the only representatives that appear abundantly in burned areas during the first 10 years. From an ecological viewpoint they are of interest because they develop quickly, forming a dense protective cover on exposed mineral soil. Either wind or water erosion of soil thus protected seems impossible.

Lichens are rare in burned areas for the first 10 years. Occasionally *Peltigera canina* var. *rufescens* and *P. canina* var. *spuria* are seen after the fourth or fifth year. The fruticose reindeer lichens seem to be completely absent.

### *Paper Birch Type*

This type represents a relatively early stage in forest succession, comparable to the quaking aspen type. It is of widespread occurrence on the uplands in the interior, being especially prominent on the Kenai Peninsula, in the Knik Arm area, in the Talkeetna Mountains, and in the Tanana Valley. Type boundaries are usually sharp, as would be expected in view of the fact that they generally mark the periphery of a fire.

The forest tree composition in the paper birch type is shown in table 3. Characteristically it is a pure type but occasionally aspen, and rarely balsam poplar, appear in the main crown canopy. Scattered white spruce, occurring in the understory, are frequently encountered in stands more than 80 years of age. Certain other trees, commercially unimportant, appear in the understory. These include thinleaf alder and Sitka alder. Both of these species are most common in mature or overmature stands. Of the willows that attain small tree size, Bebb willow and Scouler willow may be mentioned. Both are occasionally encountered in stands less than 80 years of age.

Initial stand density is very high; 3,000 to 6,000 trees per acre is not uncommon at 20 years of age. There appears to be a reasonably good expression of dominance in paper birch with the result that mortality is heavy in stands of small-pole size. By the time the stands are 50 to 60 years of age, the number of trees has dropped to

TABLE 3.—*Composition of paper birch stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up | | Diameter 10 inches and up | |
|---|---|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area | Trees per acre | Basal area |
| | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| 20-year-old stand, P51-4: | | | | | | | |
| Kenai paper birch | 2,560 | 1,320 | 51.1 | 10 | 1.4 | 0 | 0 |
| Sitka spruce | 210 | 110 | 4.7 | 0 | 0 | 0 | 0 |
| Mountain hemlock | 60 | 10 | .2 | 0 | 0 | 0 | 0 |
| Thinleaf alder | 130 | 30 | ([1]) | 0 | 0 | 0 | 0 |
| Bebb willow | 340 | 280 | ([1]) | 0 | 0 | 0 | 0 |
| 25-year-old stand, P51-6: | | | | | | | |
| Alaska paper birch | 6,360 | 2,140 | 75.0 | 20 | 2.7 | 0 | 0 |
| White spruce | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bebb willow | 180 | 60 | ([1]) | 0 | 0 | 0 | 0 |
| 40-year-old stand, P51-37: | | | | | | | |
| Alaska paper birch | 2,320 | 1,760 | 75.4 | 20 | 2.7 | 0 | 0 |
| Sitka alder | 1,000 | 420 | ([1]) | 0 | 0 | 0 | 0 |
| 55-year-old stand, P51-30: | | | | | | | |
| Alaska paper birch | 1,090 | 1,090 | 130.2 | 480 | 85.8 | 0 | 0 |
| Sitka alder | 40 | 10 | ([1]) | 0 | 0 | 0 | 0 |
| 80-year-old stands: | | | | | | | |
| P51-22: | | | | | | | |
| Alaska paper birch | 430 | 430 | 86.2 | 320 | 77.4 | 0 | 0 |
| Scouler willow | 490 | 290 | ([1]) | 100 | ([1]) | 0 | 0 |
| Bebb willow | 20 | 10 | ([1]) | 0 | 0 | 0 | 0 |
| Sitka alder | 580 | 190 | ([1]) | 0 | 0 | 0 | 0 |
| P49-21: | | | | | | | |
| Kenai paper birch | 430 | 430 | 72.5 | 240 | 60.3 | 10 | 6.6 |
| Quaking aspen | 100 | 100 | 21.4 | 70 | 18.8 | 0 | 0 |
| White spruce | 10 | 10 | 3.5 | 10 | 3.5 | 0 | 0 |
| P49-22: | | | | | | | |
| Kenai paper birch | 600 | 600 | 81.7 | 330 | 63.2 | 0 | 0 |
| Scouler willow | 10 | 10 | ([1]) | 10 | ([1]) | 0 | 0 |
| P49-23: | | | | | | | |
| Kenai paper birch | 400 | 400 | 60.2 | 210 | 51.4 | 0 | 0 |
| Quaking aspen | 340 | 340 | 48.9 | 180 | 37.9 | 0 | 0 |
| Scouler willow | 10 | 10 | ([1]) | 10 | ([1]) | 0 | 0 |
| P49-20: | | | | | | | |
| Kenai paper birch | 280 | 280 | 64.5 | 220 | 61.1 | 10 | 5.5 |
| Quaking aspen | 296 | 290 | 49.0 | 200 | 41.2 | 0 | 0 |
| White spruce | 10 | 10 | 4.4 | 10 | 4.4 | 0 | 0 |
| Scouler willow | 10 | 10 | ([1]) | 10 | ([1]) | 0 | 0 |
| 90-year-old stand, P50-12, Alaska paper birch | 510 | 510 | 127.2 | 470 | 124.4 | 30 | 22.7 |
| 110-year-old stands: | | | | | | | |
| P51-35: | | | | | | | |
| Alaska paper birch | 330 | 320 | 105.6 | 300 | 104.2 | 50 | 33.2 |
| White spruce | 130 | 120 | 13.5 | 50 | 8.1 | 0 | 0 |
| P51-38: | | | | | | | |
| Alaska paper birch | 280 | 250 | 140.1 | 240 | 139.7 | 140 | 105.2 |
| White spruce | 70 | 60 | 12.4 | 40 | 11.0 | 0 | 0 |
| Sitka alder | 330 | 110 | ([1]) | 0 | 0 | 0 | 0 |
| 120-year-old stands: | | | | | | | |
| P51-39: | | | | | | | |
| Alaska paper birch | 140 | 125 | 53.6 | 90 | 51.9 | 45 | 38.1 |
| White spruce | 25 | 25 | 7.4 | 25 | 7.4 | 0 | 0 |
| Greenes mountain-ash | 75 | 15 | ([1]) | 0 | 0 | 0 | 0 |
| Sitka alder | 530 | 195 | ([1]) | 0 | 0 | 0 | 0 |
| P51-40: | | | | | | | |
| Alaska paper birch | 400 | 320 | 106.7 | 170 | 98.1 | 80 | 74.7 |
| White spruce | 90 | 90 | 18.9 | 70 | 18.2 | 0 | 0 |
| P51-41: | | | | | | | |
| Alaska paper birch | 130 | 120 | 62.1 | 90 | 60.8 | 50 | 50.3 |
| White spruce | 50 | 50 | 11.6 | 30 | 9.9 | 0 | 0 |
| Sitka alder | 240 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Basal area not determined.

around 1,000 per acre and by 80 years to about 500. After 80 years the decrease in numbers continues, but at a less rapid rate. After 100 to 120 years, the basal area of the paper birch appears to decline and that of white spruce increases. Defect, in the form of vertical cracks (frost cracks) in the boles of the larger trees, and decay, apparently due chiefly to *Fomes igniarius* (Fr.) Kickx, become increasingly noticeable after the stands attain an age of about 100 years.

Forest-canopy density decreases after the forest stand is about 100 years old; this decrease results from death of individual birches and all aspen. Subordinate vegetation occupying strata below a height of 6 feet usually has a density of cover amounting to 30 to 60 percent. Application of the concept of stratification of vegetation was attempted in the paper birch type but without notable results. Greatest density is seen in the layer from 0 to 2 inches in height, that 2 to 12 inches in height, and the central part of the main crown canopy of the trees.

Maximum heights in the examples of mature or overmature stands that were examined seldom exceeded 80 feet and more frequently were around 70 feet. Maximum diameters were seldom over 18 to 20 inches and usually were less.

Most young paper birch stands are even aged but in the course of their development to maturity they become more uneven aged.

Tree reproduction is scanty. The average number of birch, spruce, and aspen seedlings encountered was 185, 120, and 60 per acre, respectively. Willows also are poorly represented; the average number of seedlings per acre of all species combined was only 315. The most common willows are Bebb, Scouler, and Barclay.

The most abundant shrubs, other than the willows, are the following: *Cornus canadensis, Ribes triste, Rosa acicularis, Vaccinium vitis-idaea,* and *Virburnum edule.* These occur in the majority of stands regardless of their age. From the standpoint of cover, *Cornus canadensis* and *Vaccinium vitis-idaea* are noteworthy. Less abundant, but still common, are *Menziesia ferruginea, Rubus pedatus,* and *Vaccinium cespitosum.* These species are more characteristic of stands older than 80 years than they are of young stands.

### Shrubs, Occasional to Rare

*Empetrum nigrum*
*Ledum palustre* ssp. *decumbens*
*L. palustre* ssp. *groenlandicum*
*Oplopanax horridus*
*Ribes hudsonianum*
*Rubus idaeus* var. *strigosus*
*Sambucus callicarpa*
*Sorbus scopulina*

Only one grass, *Calamagrostis canadensis,* is prominent in the paper birch type. It has a high frequency, as a rule occurring on more than 80 percent of the plots. The density of cover of this species (usually less than 10 percent) increases slightly as the stands become mature and start to open up. *Poa pratensis* was the only other grass encountered in this forest type.

Grasslike plants, especially the sedges, are practically absent.

### Forbs, Most Abundant

*Dryopteris disjuncta*
*Epilobium angustifolium*
*Equisetum pratense*
*Linnaea borealis* var. *americana*
*Lycopodium annotinum* (especially in stands more than 100 years of age)
*Pyrola asarifolia* var. *incarnata*
*P. secunda*
*Trientalis europaea* ssp. *arctica*

FORBS, COMMON

*Arenaria lateriflora* (in stands less than 100 years of age)
*Dryopteris austriaca* (in stands more than 110 years of age)
*Equisetum arvense*
*E. scirpoides* (in stands less than 80 years of age)
*E. sylvaticum* (in stands more than 110 years of age)

FORBS, OCCASIONAL TO RARE

*Aconitum delphinifolium*
*Comandra livida*
*Corallorhiza trifida*
*Goodyera repens* var. *ophioides*
*Mertensia paniculata*

The most abundant mosses are *Hylocomium splendens*, *Pleurozium schreberi*, and *Polytrichum commune*. It appears that *H. splendens* enters somewhat later than the other two species, first becoming prominent after the stands have passed an age of about 30 years. After paper birch stands have attained an age of about 100 years, species such as *Drepanocladus uncinatus*, *Eurhynchium praelongum*, and *Hypnum crista-castrensis* may be common.

MOSSES, OCCASIONAL TO RARE

*Dicranum fuscescens*
*D. majus*
*Plagiothecium denticulatum*
*Polytrichum juniperinum*
*Hypnum crista-castrensis*

Lichens are uncommon in the paper birch type. Lynge (*84*) noted that they are also rare in the *Betula odorata* forests in Norway. Fruticose lichens are especially scarce. The only lichens commonly encountered are *Peltigera aphthosa* var. *typica* and *P. aphthosa* var. *variolosa*. Rare are *Cladonia cornuta* f. *cylindrica*, *C. gracilis* var. *dilatata*, *C. scabriuscula* f. *sublevis*, *Peltigera canina* var. *rufescens*, and *P. membranacea*. In the older stands on the Kenai Peninsula and in the Susitna River basin, *Lobaria pulmonaria* is frequently seen in large masses on trees. There are indications that the lichens (other than the peltigeras) decrease with increasing stand age.

Paper birch, in essentially pure stands, is a fire type. The species seeds in on burned areas and even-aged forests result. Melechow (*92*) reported that in burns on the Dwina River in Russia, birch reproduction came in over a period of about 14 years following fires; establishment of reproduction reached a peak about 11 to 13 years after burning. Seedbed conditions under full stands of paper birch appear unfavorable for germination and initial survival of seedlings of the species. It also appears that there is insufficient sunlight for seedling development under birch canopies. There were no indications that birch will follow birch in successive generations in the absence of fire or other catastrophic disturbance. On the other hand, there is abundant evidence that white spruce seed is capable of germinating and that spruce seedlings can develop, if slowly, in birch forests. Barring disturbances such as fire, paper birch stands are gradually converted into white spruce-paper birch forests.

Fires in birch forests tend to perpetuate the birch and reduce the representation of spruce. Following fires there is usually some sprouting of birch stumps, but the principal reason for the decline in spruce is the lack of seed of the species. The proportion of spruce which bear seed in birch stands is low because most of the trees are in the understory and only a few have their tops in a position to receive direct sunlight. Under these conditions spruce regeneration can come only from seed blown in from adjacent unburned stands.

## *White Spruce-Paper Birch Type*

The white spruce-paper birch type (fig. 13) represents a stage of succession comparable to the white spruce-quaking aspen type. It is more advanced in terms of succession than either the paper birch type, the quaking aspen type, or the balsam poplar type. It occurs widely on the uplands, probably occupying more area than the paper birch type. Type boundaries are less well defined than in pure birch stands; transition to pure birch or pure spruce is frequently found.

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FIGURE 13.—A white spruce-Alaska paper birch stand, approximately 110 years old.

In the white spruce-paper birch type these species are invariably the dominants but the relative proportion of each varies considerably from stand to stand (table 4). This results partly from the fact that in some stands spruce became established at the same time the birch seeded in, whereas in other stands the birch came in first and spruce later developed under the tree canopy. In no instance did birch invade stands that were initially pure spruce. Quaking aspen is commonly present as scattered individuals in young stands but is poorly represented in forests more than about 120 to 140 years of age. Species such as black cottonwood, balsam poplar, Bebb willow, and Sitka alder occur as minor species, chiefly in the understory in young stands. Initial stand densities are usually high with around 2,500 spruce and birch trees per acre at 25 years of age. Mortality, especially in the birch, is high with the result that when the stands have attained an age of around 100 years the number of trees has declined to around 500 to 700 per acre.

The basal area of spruce, which tends to be lower than that of birch in young stands, gradually increases and finally exceeds that of birch after the stand attains an age of around 130 years. Defect due to decay in the birch is noticeable in stands around 100 years of age and becomes very prominent thereafter.

Forest-canopy density is high in stands up to about 100 years of age but thereafter it decreases. In the subordinate vegetation, density is greatest in the ground layer, up to 2 inches in height, where 50 to 75 percent of the surface is occupied. Density is least, usually less than 10 percent, in the layers from 1 to 2.5 and 2.5 to 6 feet in height.

Maximum heights in the mature and overmature stands of white spruce-paper birch seldom exceed 65 to 75 feet for spruce and 60 to 70 feet for birch. Maximum diameters in spruce are usually less than 13 inches and in birch 15 inches.

Young stands tend to be even aged but with the passage of time they become uneven aged due to the entry of more spruce and the gradual opening of the stands after 100 years. The birch is usually essentially even aged.

Reproduction of tree species was scanty. Only in the case of white spruce were as many as 40 percent of the plots stocked with seedlings; these were in stands less than 140 years old. Older stands were practically lacking in trees less than 6 feet in height. Willows too were scarce; Bebb willow and Scouler willow were the only ones represented.

The most abundant shrubs, other than willows, are *Cornus canadensis*, *Rosa acicularis*, *Vaccinium vitis-idaea*, and *Viburnum edule*, which are found in every stand. All these species have a very high frequency (usually 80 percent or more) but have a relatively low density of cover (usually less than 10 percent). *Rubus pedatus* occurs commonly in stands more than 140 years of age but is practically absent in younger stands. It was absent from paper birch forests less than about 120 years of age. *Ribes triste* is also relatively common. Occasional to rare are *Arctostaphylos uva-ursi*, *Empetrum nigrum*, *Ledum palustre* ssp. *decumbens*, *L. palustre* ssp. *groenlandicum*, *Menziesia ferruginea* (only in stands more than 140 years of age), *Sorbus scopulina* (only in stands more than 140 years of age), and *Spiraea beauverdiana*.

TABLE 4.—*Composition of white spruce-paper birch stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up | | Diameter 10 inches and up | |
|---|---|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area | Trees per acre | Basal area |
| 24-year-old stands: | | | | | | | |
| P51-2: | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| White spruce | 440 | 270 | 10.0 | 0 | 0 | 0 | 0 |
| Kenai paper birch | 2,040 | 1,420 | 64.2 | 60 | 10.6 | 0 | 0 |
| Quaking aspen | 60 | 40 | 2.0 | 0 | 0 | 0 | 0 |
| Balsam poplar | 10 | 10 | .2 | 0 | 0 | 0 | 0 |
| Bebb willow | 630 | 40 | (1) | 0 | 0 | 0 | 0 |
| P51-3: | | | | | | | |
| White spruce | 1,280 | 180 | 5.1 | 0 | 0 | 0 | 0 |
| Kenai paper birch | 1,200 | 600 | 33.7 | 20 | 5.4 | 0 | 0 |
| Quaking aspen | 80 | 40 | 3.7 | 20 | (1) | 0 | 0 |
| Balsam poplar | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bebb willow | 1,060 | 400 | (1) | 0 | 0 | 0 | 0 |
| Sitka alder | 240 | 80 | (1) | 0 | 0 | 0 | 0 |
| 105-year-old stand, P51-7: | | | | | | | |
| White spruce | 220 | 220 | 36.2 | 150 | 32.5 | 0 | 0 |
| Alaska paper birch | 500 | 490 | 98.5 | 390 | 93.0 | 0 | 0 |
| Quaking aspen | 20 | 20 | 8.8 | 20 | 8.8 | 0 | 0 |
| 110-year-old stand, P51-36: | | | | | | | |
| White spruce | 300 | 300 | 101.9 | 250 | 99.4 | 50 | 38.9 |
| Alaska paper birch | 180 | 180 | 34.6 | 150 | 33.0 | 10 | 5.5 |
| Bebb willow | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| 130-year-old stand, P50-1: | | | | | | | |
| White spruce | 860 | 830 | 115.8 | 350 | 90.0 | 20 | 12.1 |
| Kenai paper birch | 300 | 300 | 29.5 | 90 | 19.5 | 0 | 0 |
| Quaking aspen | 110 | 110 | 27.0 | 110 | 27.0 | 10 | 5.5 |
| 140-year-old stand, P50-2: | | | | | | | |
| White spruce | 750 | 630 | 89.3 | 240 | 71.0 | 40 | 24.2 |
| Kenai paper birch | 120 | 120 | 19.8 | 70 | 17.2 | 0 | 0 |
| Quaking aspen | 110 | 110 | 36.1 | 90 | 34.4 | 20 | 15.8 |
| 145-year-old stand, P49-18: | | | | | | | |
| White spruce | 350 | 350 | 57.6 | 180 | 47.9 | 10 | 7.9 |
| Kenai paper birch | 210 | 210 | 91.7 | 200 | 91.2 | 80 | 50.7 |
| Quaking aspen | 10 | 10 | 4.4 | 10 | 4.4 | 0 | 0 |
| 155-year-old stands: | | | | | | | |
| P49-16: | | | | | | | |
| White spruce | 420 | 420 | 91.4 | 260 | 81.9 | 20 | 14.7 |
| Kenai paper birch | 160 | 160 | 77.1 | 140 | 75.8 | 80 | 51.9 |
| P49-17: | | | | | | | |
| White spruce | 260 | 250 | 70.2 | 190 | 65.7 | 30 | 17.5 |
| Kenai paper birch | 180 | 180 | 90.7 | 180 | 90.7 | 70 | 52.1 |
| Black cottonwood | 10 | 10 | 6.6 | 10 | 6.6 | 10 | 6.6 |
| P49-19: | | | | | | | |
| White spruce | 450 | 440 | 97.5 | 390 | 89.5 | 30 | 18.8 |
| Kenai paper birch | 190 | 190 | 85.0 | 190 | 85.0 | 80 | 54.3 |
| Quaking aspen | 20 | 20 | 7.0 | 20 | 7.0 | 0 | 0 |
| 190-year-old stand, P51-8: | | | | | | | |
| White spruce | 210 | 210 | 67.2 | 190 | 65.4 | 40 | 23.0 |
| Alaska paper birch | 250 | 220 | 66.6 | 140 | 62.0 | 50 | 38.0 |

[1] Basal area not determined.

*Calamagrostis canadensis* is the only important grass in white spruce-paper birch forests. It is absent or rare in young stands but appears in old stands when they begin to open up. Grasslike plants are practically absent.

The most abundant forbs are *Comandra livida*, *Dryopteris disjuncta* (especially in old stands), *Epilobium angustifolium*, *Equisetum arvense* (in stands more than 140 years of age), *Goodyera repens* var. *ophioides*, *Linnaea borealis* var. *americana*, *Listera cordata* (in old stands), *Lycopodium annotinum*, *Pyrola asarifolia* var. *incarnata* (especially in forests more than 100 years of age), *P. secunda*, and *Trientalis europaea* ssp. *arctica*.

FORBS, OCCASIONAL TO RARE

| | |
|---|---|
| *Achillea borealis* | *Lycopodium clavatum* var. *monostachyon* |
| *Arenaria lateriflora* | *L. complanatum* |
| *Equisetum pratense* | *Moneses uniflora* |
| *Lupinus nootkatensis* | *Streptopus amplexifolius* |
| *L. polyphyllus* | |

Mosses in the white spruce-paper birch forest are similar to those in the paper birch type. *Hylocomium splendens*, *Pleurozium schreberi*, and *Polytrichum commune* are by far the most abundant. Density of coverage is greatest for *Pleurozium schreberi*, 25 percent of the forest floor usually being occupied by this species.

MOSSES, OCCASIONAL TO RARE

| | |
|---|---|
| *Aulacomnium turgidum* | *Pohlia nutans* |
| *Dicranum fuscescens* | *Hypnum crista-castrensis* |
| *D. majus* | *Rhytidiadelphus triquetrus* |
| *Drepanocladus uncinatus* | |

The liverwort *Ptilidium ciliare* is also occasionally encountered.

Lichens are poorly represented and poorly developed in the white spruce-paper birch type. The only species at all frequently encountered is *Peltigera aphthosa* var. *typica*.

LICHENS, OCCASIONAL TO RARE

| | |
|---|---|
| *Cladonia cornuta* f. *cylindrica* | *C. uncialis* |
| *C. gracilis* var. *dilatata* | *Peltigera membranacea* |
| *C. scabriuscula* f. *adspersa* | *Stereocaulon tomentosum* |

As in paper birch stands, there appears to be a decline in the lichen population, other than species of *Peltigera*, as the stands increase in age.

White spruce-paper birch stands may develop immediately after fires or they may result from gradual entry of white spruce into paper birch stands which originally were pure. The nature of the seed source available following fires appears to determine in large measure which of the two situations will prevail. Birch does not seem to be a very favorable nurse crop or associate for white spruce. Like all other forest species in the interior of Alaska, white spruce develops best when provided with mineral seedbeds and full or nearly full sunlight. Under birch canopies, light conditions are almost certainly below the optimum for spruce. The result is that juvenile growth of understory spruce is slow. As the spruce crowns gradually enter the strata occupied by the birch, another unfavorable influence is encountered. Crown friction is so great that the spruce is deformed, often beyond recovery. Birch crowns appear to be especially damaging in this respect. Young birch trees whip and sway and the branches in the crowns of the large birches also undergo much movement even in comparatively light winds. Although conditions are not very favorable for development of white spruce in birch stands, they are even less so for birch reproduction. In the absence of fire or cutting, white spruce-paper birch stands gradually change to relatively open, essentially pure, white spruce stands. George Cartwright in his Labrador Journal, published in 1792 (*156*), described a closely parallel successional development involving replacement of birch by spruce and fir.

Fires tend to perpetuate the birch and reduce the proportion of spruce, as explained for the paper birch type. Here, however, birch is not favored as much, and spruce is not repressed as greatly. The older, larger birch does not reproduce as well vegetatively as does younger, smaller birch, and in most of the white spruce-paper birch stands the spruce is more likely to have begun to bear seed.

## *Quaking Aspen Type*

The quaking aspen type represents a stage of succession comparable to the paper birch type. The type is very widespread on upland areas in the interior of Alaska and is particularly common on relatively dry slopes with south or southwest exposures, and on other excessively drained situations. Raup (*124*), while working along the Alaska Highway, repeatedly observed aspen on warm south-facing slopes; on these situations it appeared to him that the type tends to persist for long periods. Excessive drainage, although evidently favoring quaking aspen more than white spruce or paper birch, generally leads to poor, slowly growing, rather open stands. Boundaries of the quaking aspen type are often very sharp, marking the peripheries of old fires.

TABLE 5.—*Composition of quaking aspen stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up [1] | |
|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area |
| | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| 20-year-old stand, P51-15, quaking aspen | 6,120 | 1,120 | 27.3 | 0 | 0 |
| 25-year-old stands: | | | | | |
| T50-7: | | | | | |
| Quaking aspen | 3,750 | 1,750 | 72.9 | 0 | 0 |
| Bebb willow | 1,350 | 0 | 0 | 0 | 0 |
| P51-25: | | | | | |
| Quaking aspen | 3,540 | 1,380 | 42.9 | 0 | 0 |
| Bebb willow | 530 | 0 | 0 | 0 | 0 |
| Scouler willow | 140 | 0 | 0 | 0 | 0 |
| 30-year-old stand, P50-22: | | | | | |
| Quaking aspen | 220 | 50 | 1.1 | 0 | 0 |
| Alaska paper birch | 80 | 40 | 1.4 | 0 | 0 |
| White spruce | 60 | 20 | .4 | 0 | 0 |
| Balsam poplar | 30 | 0 | 0 | 0 | 0 |
| Bebb willow | 290 | 20 | (2) | 0 | 0 |
| Littletree willow | 380 | 40 | (2) | 0 | 0 |
| Scouler willow | 70 | 0 | 0 | 0 | 0 |
| American green alder | 180 | 0 | 0 | 0 | 0 |
| 50-year-old stand, P51-1: | | | | | |
| Quaking aspen | 1,040 | 900 | 89.6 | 320 | 58.2 |
| White spruce | 180 | 0 | 0 | 0 | 0 |
| Scouler willow | 460 | 410 | (2) | 0 | 0 |
| 60-year-old stands: | | | | | |
| P51-14: | | | | | |
| Quaking aspen | 2,800 | 2,040 | 85.9 | 60 | 9.4 |
| Balsam poplar | 480 | 440 | 32.6 | 60 | 9.4 |
| Bebb willow | 60 | 40 | (2) | 0 | 0 |
| P51-27: | | | | | |
| Quaking aspen | 850 | 620 | 65.1 | 270 | 42.2 |
| Alaska paper birch | 70 | 60 | 5.8 | 10 | 1.4 |
| Balsam poplar | 20 | 0 | 0 | 0 | 0 |
| Bebb willow | 50 | 30 | (2) | 0 | 0 |

[1] No trees reached 10 inches in diameter.
[2] Basal area not determined.

Tree composition in the quaking aspen type is illustrated in table 5. Associated with the aspen are white spruce, Alaska paper birch or Kenai paper birch, and balsam poplar. Representation of these species is usually poor and bears no discernible relation to site. Other associates, in understory position, are Bebb willow, Scouler willow, littletree willow, and American green alder. The willows are most common in young stands, less than about 40 years of age. Initial densities may be very high, 3,000 to 6,000 stems 1 inch and larger in diameter being found per acre in stands around 20 to 25 years old (fig. 14). Even in stands 50 to 60 years old there are frequently 1,000 to 3,000 stems per acre. Mortality of aspen is high in trees 1 to 2 inches in diameter, but new sprouts continue to issue from the roots, particularly in young stands. After stands are about 60 years old, decay becomes very common and they start to open up as trees die.

Forest-canopy density appears to decrease with increasing stand age. In the subordinate vegetation the greatest density is found in the ground layer (0 to 2 inches) where about 35 percent of the surface is occupied. Density is least in the layers 1 to 2.5 feet and 2.5 to 6 feet above the ground level. Vegetation density in these layers is usually less than 10 percent.

F-477368

FIGURE 14.—A 20-year-old quaking aspen stand. The dominants are 2 to 3 inches d. b. h. and 25 to 30 feet tall.

Maximum heights in the oldest stands classified as pure aspen seldom exceeded 60 feet and maximum diameters were usually less than 10 inches. These values do not represent the maximum sizes attained by aspen in the interior of Alaska. With increasing age, size also increases (especially diameter) but the stands are then likely to be classified as white spruce-quaking aspen.

Aspen stands are essentially even aged, but as they pass into the white spruce-quaking aspen type they tend to become uneven aged.

Birch reproduction is almost lacking in aspen stands, and white spruce reproduction tends to be sparse unless a good seed source is near. Aspen reproduction averages around 1,400 individuals per acre, but these are mostly root suckers which soon die. Of the willows, Bebb willow is most abundant, especially in stands less than 40 years of age. Blueberry and Scouler willows are occasionally encountered.

The most abundant shrubs, other than willows, are *Arctostaphylos uva-ursi* (present in every stand), *Rosa acicularis*, *Shepherdia canadensis*, and *Vaccinium vitis-idaea*.

### SHRUBS, OCCASIONAL TO RARE

*Arctostaphylos alpina* ssp. *rubra*
*Betula glandulosa*
*Cornus canadensis*
*Empetrum nigrum*
*Ledum palustre* ssp. *groenlandicum*
*Rubus idaeus* var. *strigosus*
*Vaccinium cespitosum*
*V. uliginosum*
*Viburnum edule*

A wider variety of grasses is encountered in aspen stands than in the paper birch or white spruce-paper birch forests. Presumably this results from the more open canopies in most aspen communities. The most prominent grasses are *Agrostis scabra*, *Calamagrostis canadensis*, and *Festuca altaica*. Of these the last two have the highest density, often 10 to 50 percent. Other occasional to rare species, which appear in relatively mature stands, are *Bromus pumpellianus*, *Calamagrostis purpurascens*, and *Poa glauca*.

Grasslike plants are very rare in aspen stands. Occasionally species such as *Carex concinna* and *C. supina* ssp. *spaniocarpa* are seen.

Forb species represented are listed below.

### FORBS, MOST ABUNDANT

*Achillea borealis*
*Epilobium angustifolium*
*Equisetum scirpoides*
*Linnaea borealis* var. *americana*
*Mertensia paniculata*

### FORBS, COMMON

*Lupinus arcticus*
*Pyrola secunda*
*Zigadenus elegans*

Forbs, Occasional to Rare

*Arenaria lateriflora*
*Aster sibericus*
*Bupleurum americanum*
*Comandra livida*
*Equisetum pratense*
*Galium boreale*
*Geranium erianthum*
*Lycopodium annotinum*
*L. clavatum* var. *monostachyon*
*L. complanatum*
*Pedicularis sudetica*
*Polemonium boreale*
*Pyrola asarifolia* var. *incarnata*
*Saxifraga tricuspidata*
*Solidago multiradiata*

Mosses do not attain the density of cover in aspen stands that they do in paper birch and white spruce forests. Density of cover in a given species seldom exceeds 5 percent. No species were found abundant.

Mosses, Occasional to Rare

*Aulacomnium turgidum*
*Bryum cuspidatum*
*Camptothecium lutescens*
*Campylium stellatum*
*Drepanocladus uncinatus*
*Hylocomium splendens*
*Polytrichum commune*
*P. juniperinum*
*P. strictum*

A liverwort, *Ptilidium ciliare*, is occasionally seen.

The lichen population in aspen stands is considerably greater than in paper birch or white spruce-paper birch; perhaps this is because aspen forests are more open. The lichen cover appears to decrease slightly after the stands attain an age of about 30 years. No single lichen species is especially abundant or characteristic.

Lichens, Occasional to Rare

*Cetraria cucullata*
*C. nivalis*
*Cladonia alpestris*
*C. cariosa* f. *cribrosa*
*C. cenotea* f. *crossota*
*C. chlorophaea* f. *simplex*
*C. coccifera*
*C. coniocraea* f. *stenoscypha*
*C. cornuta* f. *cylindrica*
*C. degenerans* f. *euphorea*
*C. furcata* var. *racemosa*
*C. gracilis* var. *dilatata*
*C. gracilis* var. *elongata* f. *laontera*
*C. lepidota*
*C. multiformis* f. *simulata*
*C. multiformis* f. *subascypha*
*C. squamosa* f. *muricella*
*C. uncialis*
*Nephroma arcticum*
*N. expallidum*
*Peltigera aphthosa* var. *typica*
*P. canina* var. *rufescens*
*P. malacea*
*Stereocaulon paschale*
*S. paschale* var. *grande* f. *velutinum*
*S. tomentosum*

Aspen stands develop following fires. Regeneration is from seedlings and root suckers, with few, if any, stump sprouts. Abundant vegetative reproduction from root suckers almost invariably follows on burned areas formerly supporting aspen. In areas where aspen was absent or scarce in the previous stand, reproduction, if any, is of seed origin. Aspen seeds are borne in large numbers and are easily disseminated, but fairly close proximity to a seed source seems essential for the establishment of seedlings in quantity. Even-aged stands are characteristic.

In the absence of fire or other comparable disturbance, aspen does not follow aspen; a possible exception may be found on excessively dry slopes having a southerly or westerly exposure. On such sites, Stoeckeler (*147*) regards aspen as the climax. White spruce, which may have started with the aspen immediately after a fire or which more usually entered the stand later, gradually dominates the site. Aspen is an intolerant, short-lived species as compared with white spruce, which is relatively long lived and tolerant. White spruce is evidently subjected to less suppression and less deformation of crowns in aspen than in paper birch forests.

Fires in aspen stands perpetuate aspen and destroy practically all the white spruce that may have entered the stands. Spruce is greatly handicapped in surviving fires because the living branches are close to the ground, the bark is thin, and the species is strictly dependent on seedling reproduction. In the Lake States, Stoeckeler (*148*) found that repeat burns in established aspen stands reduce site index from 6 to 25 feet.

### *White Spruce-Quaking Aspen Type*

This type represents a stage of successional development directly analogous to the white spruce-paper birch type. It is widely represented on the uplands in the interior, perhaps being most common on relatively dry slopes having a south or southwest exposure and on excessively drained outwash or delta soils. On the drier situations, entry of white spruce into aspen stands is slower, and subsequent development is less rapid than on sites with favorable moisture relations.

In the white spruce and quaking aspen type these species are the dominants, but the relative proportion of the two species varies substantially from stand to stand (table 6). This usually is due to composition of the reproduction at the time the stand was established and to the rate of subsequent invasion of spruce. On sites of average or better than average quality, white spruce frequently comes in at the same time the aspen is established, that is, shortly after a fire.

With a source of seed available, white spruce seedlings become established on good sites. On the poorer, dry sites, white spruce establishment immediately after a fire is difficult, and in such situations spruce slowly reenters the area under the canopy of the aspen (fig. 15). This process is evidently very slow on steep slopes having a south or southwest exposure. Associated with white spruce and quaking aspen are balsam poplar and several willows of which Bebb willow is usually the most important. As a group, willows are present to the extent of about 8,700 stems per acre; about 6,400 of these are Bebb willow. Other willows encountered are Barclay willow, including var. *hebecarpa*, blueberry willow, and Scouler willow. Initial stand densities are high, with 1,000 to 2,000 white spruce and quaking aspen stems per acre at 20 years. By the time the stands have attained an age of about 100 years, the number of stems per acre has declined to around 400 to 600. White spruce gains in importance with increase in stand age whereas the importance of aspen declines (fig. 16). In one white spruce-quaking aspen stand 115 years old, there were 210 living and 690 dead aspen trees per acre in diameter classes above 3 inches. In this same stand there was essentially no mortality in white spruce, and the trees appeared thrifty.

Table 6.—*Composition of white spruce-quaking aspen stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up | | Diameter 10 inches and up | |
|---|---|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area | Trees per acre | Basal area |
| 20-year-old stands: | | | | | | | |
| P49-24: | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| White spruce | 260 | 170 | 6.9 | 0 | 0 | 0 | 0 |
| Quaking aspen | 2,040 | 850 | 18.1 | 0 | 0 | 0 | 0 |
| Bebb willow | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| P49-25: | | | | | | | |
| White spruce | 250 | 140 | 8.1 | 20 | 2.7 | 0 | 0 |
| Quaking aspen | 870 | 490 | 18.0 | 0 | 0 | 0 | 0 |
| Bebb willow | 700 | 0 | 0 | 0 | 0 | 0 | 0 |
| P49-26: | | | | | | | |
| White spruce | 570 | 410 | 34.5 | 120 | 19.5 | 0 | 0 |
| Quaking aspen | 1,610 | 710 | 20.7 | 0 | 0 | 0 | 0 |
| Black cottonwood | 40 | 10 | .5 | 0 | 0 | 0 | 0 |
| P49-27: | | | | | | | |
| White spruce | 760 | 550 | 47.5 | 130 | 25.4 | 0 | 0 |
| Quaking aspen | 170 | 90 | 2.8 | 0 | 0 | 0 | 0 |
| Balsam poplar | 70 | 40 | 1.7 | 0 | 0 | 0 | 0 |
| 60-year-old stand, P51-13: | | | | | | | |
| White spruce | 200 | 140 | 10.6 | 40 | 7.3 | 0 | 0 |
| Quaking aspen | 450 | 450 | 96.4 | 360 | 90.0 | 10 | 5.5 |
| Balsam poplar | 10 | 10 | 3.5 | 10 | 3.5 | 0 | 0 |
| Bebb willow | 410 | 150 | (1) | 0 | 0 | 0 | 0 |
| 65-year-old stand, P50-4: | | | | | | | |
| White spruce | 990 | 820 | 87.2 | 290 | 59.1 | 0 | 0 |
| Quaking aspen | 370 | 360 | 59.4 | 190 | 49.6 | 0 | 0 |
| Balsam poplar | 10 | 10 | 2.7 | 10 | 2.7 | 10 | 2.7 |
| Bebb willow | 270 | 270 | (1) | 270 | (1) | 0 | 0 |
| 90-year-old stand, P50-13: | | | | | | | |
| White spruce | 190 | 190 | 40.0 | 110 | 34.5 | 10 | 10.9 |
| Quaking aspen | 390 | 380 | 106.3 | 300 | 100.4 | 60 | 36.2 |
| Balsam poplar | 130 | 120 | 25.0 | 80 | 21.9 | 10 | 11.0 |
| Bebb willow | 90 | 10 | (2) | 0 | 0 | 0 | 0 |
| 115-year-old stand, P50-6: | | | | | | | |
| White spruce | 130 | 130 | 30.1 | 100 | 27.9 | 10 | 11.0 |
| Quaking aspen | 230 | 210 | 81.0 | 180 | 78.8 | 60 | 38.7 |
| Balsam poplar | 210 | 80 | 1.7 | 0 | 0 | 0 | 0 |

[1] Basal area not determined.

Forest-canopy density tends to be low in stands of this type, especially when the aspen begins to drop out after about 100 years. In the subordinate vegetation, density is greater in stands less than 60 years old than in older forests. The ground layer (0 to 2 inches in height) has the highest density, and the layers 1 to 2.5 feet and 2.5 to 6.0 feet in height have the lowest density.

Maximum heights in the mature and overmature stands of white spruce-quaking aspen seldom exceeded 60 to 70 feet for spruce and 65 to 75 for quaking aspen. Maximum diameters in spruce and aspen were seldom more than 10 to 12 inches.

White spruce is uneven aged in most stands whereas the aspen is essentially even aged. The spread of ages in spruce increases with increase in stand age.

Spruce reproduction is present in all stands, but the number of trees per acre is low, ranging from 200 to 6,800 per acre and averaging 1,100. Aspen root suckers averaged about 1,600 shoots per acre. These shoots appear, live a few years, and then die. Birch reproduction is very scanty and balsam poplar is only occasionally encountered. It is obvious that, of these four species, white spruce is the only one capable of surviving and developing under the forest canopy.

F-477367

Figure 15.—A 65-year-old quaking aspen stand with an understory of black spruce and white spruce. The dominant quaking aspen trees are 4 to 9 inches d. b. h. and 45 to 50 feet tall. The spruce trees in the understory are 2 to 4 inches d. b. h. and 25 to 30 feet tall. Arrows point to aspen barked by moose. Kenai Peninsula, 1950.

### Most Abundant Shrubs, Other Than the Willows

*Arctostaphylos uva-ursi*
*Cornus canadensis*
*Rosa acicularis*
*Shepherdia canadensis*
*Vaccinium vitis-idaea*

### Shrubs, Occasional to Rare

*Arctostaphylos alpina* ssp. *rubra*
*Betula glandulosa*
*Empetrum nigrum*
*Ledum palustre* ssp. *decumbens*
*L. palustre* ssp. *groenlandicum*
*Potentilla fruticosa*
*Vaccinium cespitosum*
*Viburnum edule*

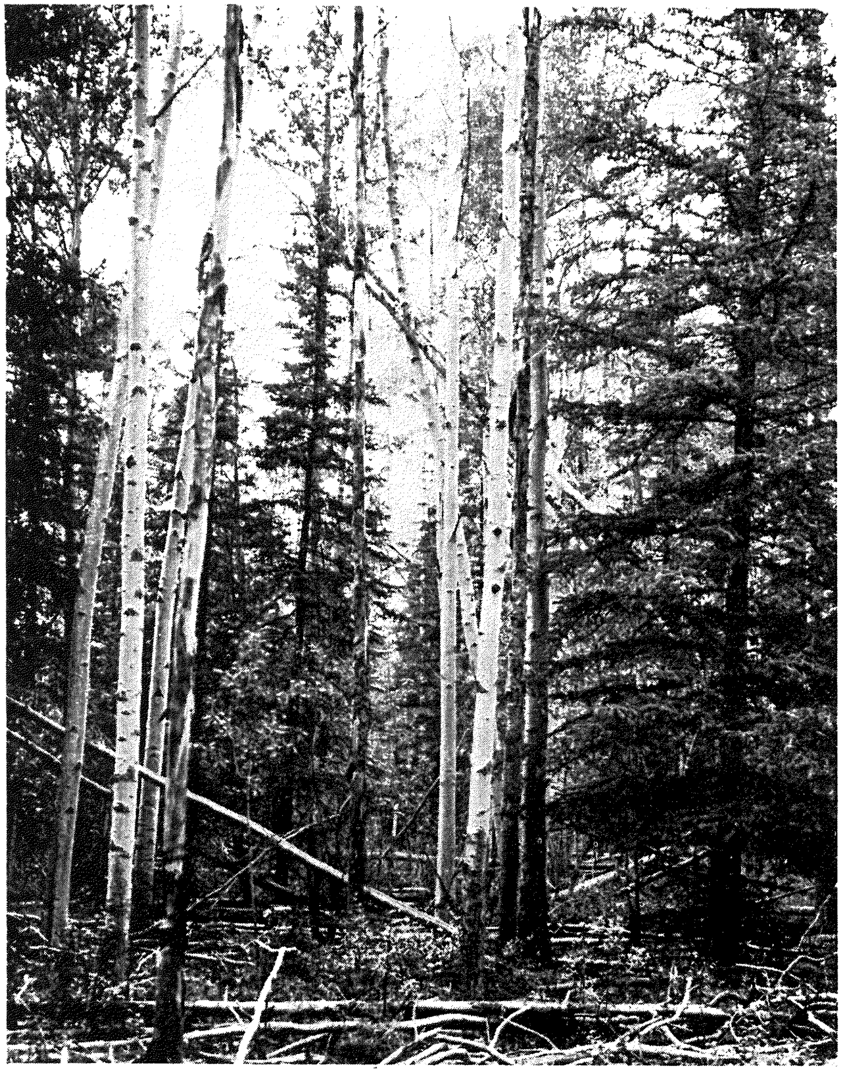
The most prominent grass is *Calamagrostis canadensis*, which occurs most commonly in the young stands. *Agrostis scabra* and *Festuca altaica* occur rarely. Grasslike plants are even more scarce than the grasses; *Carex concinna* was about the only species encountered.

### Forbs, Most Abundant

*Epilobium angustifolium*
*Linnaea borealis* var. *americana*
*Pyrola secunda*

### Forbs, Common

*Equisetum scirpoides*
*Lupinus nootkatensis*
*Moneses uniflora*
*Pyrola asarifolia* var. *incarnata*
*Trientalis europaea* ssp. *arctica*



F–477369

FIGURE 16.—A quaking aspen-white spruce stand in which the dominant quaking aspen trees are approximately 115 years of age, 8 to 12 inches d. b. h., and 60 feet tall. The white spruce trees are 5 to 11 inches d. b. h. and 40 to 50 feet tall. Much of the quaking aspen is dead or decadent.

FORBS, OCCASIONAL TO RARE

*Achillea borealis*
*Aconitum delphinifolium*
*Arenaria lateriflora*
*Castilleja pallida* ssp. *mexiae*
*Comandra livida*
*Dryopteris disjuncta*
*Equisetum pratense*
*E. sylvaticum*
*Galium boreale*
*Habenaria obtusata*
*Lupinus arcticus*
*Lycopodium annotinum*
*Mertensia paniculata*
*Pedicularis labradorica*
*Pyrola virens*
*Sanguisorba stipulata*
*Senecio integerrimus*
*Stellaria longipes*
*Viola renifolia* var. *brainerdii*

Mosses are more prominent in the white spruce-quaking aspen type than in the pure aspen forest. The most abundant species are *Drepanocladus uncinatus*, *Hylocomium splendens*, and *Polytrichum commune*. *P. commune* is most prominent in young stands whereas *H. splendens* is most abundant in old stands.

MOSSES, OCCASIONAL TO RARE

*Ceratodon purpureus*
*Climacium dendroides*
*Dicranum drummondii*
*D. fragilifolium*
*D. fuscescens*
*Ditrichum flexicaule*
*Eurhynchium praelongum*
*Pleurozium schreberi*
*Pohlia nutans*
*Polytrichum strictum*
*Tomenthypnum nitens*

Of the lichens, *Peltigera aphthosa* var. *typica* and *P. aphthosa* var. *variolosa* are most abundant. In some young stands less than 25 years of age, *Cladonia cenotea* f. *crossota* and *C. crispata* var. *infundibulifera* are common.

LICHENS, OCCASIONAL TO RARE

*Cetraria islandica*
*Cladonia cornuta* f. *cylindrica*
*C. crispata* var. *virgata*
*C. gracilis* var. *chordalis* f. *leucochlorea*
*C. gracilis* var. *dilatata*
*C. gracilis* var. *elongata* f. *laontera*
*C. mitis*
*C. pyxidata* var. *pocillum*
*C. sylvatica*
*Stereocaulon tomentosum*

White spruce-quaking aspen communities may become established immediately following fires but more characteristically they arise as a result of succession with the spruce gradually invading essentially pure aspen communities. Spruce seeds can germinate and the seedlings can survive and develop slowly under the aspen crowns. In the absence of fire or other devastating disturbance, spruce gradually replaces aspen and relatively open spruce stands are the end result. Garman (*47*) stated that in central British Columbia the elimination of aspen from mixed stands becomes rapid after an age of 60 years is reached. Millar (*97*) reported that in the "clay belt" in Ontario growth in aspen stands is balanced by mortality at about 100 years of age and from then on the aspen begins to disappear. The spruce, on the other hand, continues to grow.

Fires in the type are far more destructive of spruce than of aspen. The reasons for the selectivity of fire have already been mentioned for other types. They include principally such characteristics as thin bark, flammable foliage carried well down toward the ground, and inability of spruce to reproduce by sprouting. The rapid height

growth and early seed production of aspen root suckers gives it an advantage over spruce in recovery from fires. Severe fires in the white spruce-quaking aspen type usually lead to pure aspen stands with most of the regeneration of root sucker origin.

### *Balsam Poplar Type*

Balsam poplar in essentially pure stands is a forest type characteristic of recently deposited alluvium and is found along most of the larger rivers in the interior of Alaska. Many stands represent the first forest stage in a primary successional series. For reasons that are not apparent, balsam poplar is especially well adapted for reproduction on alluvial bars. These are a common feature along most of the Alaskan rivers that are fed by the melt water from glaciers. Aspen, which might be expected in these habitats, is a rare species. Occasionally balsam poplar spreads from its characteristic stream valley habitat to adjacent upland sites that have been swept by fires.

Forest composition in this type is indicated by the few samples presented in table 7. Balsam poplar stands are often pure but in many of them white spruce becomes an important element, especially in old stands (fig. 17). Alaska paper birch is a less important and less common associate. Small understory species such as Sitka alder, American green alder, thinleaf alder, littletree willow, feltleaf willow, and Scouler willow are occasionally encountered. Initial densities are commonly high, with as many as 3,500 trees per acre at 25 years of age. Density tends to remain high even in mature forests. Decay appears common in old stands.

Maximum heights of balsam poplar in the stands studied did not exceed about 70 feet, and maximum diameters about 36 inches. However, substantially larger trees occurred in some of the better stands in the Susitna basin. Thomas (*153*) stated that in his journey

TABLE 7.—*Composition of balsam poplar stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up | | Diameter 10 inches and up | |
|---|---|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area | Trees per acre | Basal area |
| | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| 25-year-old stand, P51-10, balsam poplar | 3,480 | 360 | 8.5 | 0 | 0 | 0 | 0 |
| 100-year-old stand, P50-17: | | | | | | | |
| Balsam poplar | 690 | 690 | 162.9 | 560 | 152.3 | 20 | 10.9 |
| White spruce | 70 | 70 | 21.4 | 60 | 20.6 | 20 | 12.1 |
| Sitka alder | 50 | 50 | (1) | 0 | 0 | 0 | 0 |
| American green alder | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 40 | 10 | (1) | 0 | 0 | 0 | 0 |
| Feltleaf willow | 120 | 20 | (1) | 0 | 0 | 0 | 0 |
| 150-year-old stand, P50-20: | | | | | | | |
| Balsam poplar | 510 | 510 | 171.4 | 500 | 170.5 | 110 | 74.1 |
| Thinleaf alder | 320 | 100 | (1) | 0 | 0 | 0 | 0 |
| Littletree willow | 40 | 40 | (1) | 0 | 0 | 0 | 0 |
| 200-year-old stand, P51-9: | | | | | | | |
| Balsam poplar | 90 | 90 | 143.9 | 90 | 143.9 | 90 | 143.9 |
| White spruce | 250 | 250 | 84.0 | 200 | 81.8 | 80 | 56.1 |
| Alaska paper birch | 120 | 120 | 24.8 | 60 | 22.4 | 30 | 16.4 |
| Scouler willow | 10 | 10 | (1) | 10 | (1) | 0 | 0 |

[1] Basal area not determined.

F-477370

FIGURE 17.—A balsam poplar-white spruce stand. The oldest poplars are 200 years of age and are nearly 30 inches d. b. h. and 75 feet tall. The oldest white spruce are 105 years of age, 13 inches d. b. h., and 70 feet tall. On Matanuska River, near Palmer, 1951.

along the Susitna River he occasionally saw cottonwood trees from 3 to 6 feet in diameter. Balsam poplar stands are often even aged but may also exhibit a considerable range in age.

Reproduction within a stand is generally sparse with only occasional white spruce, balsam poplar, and rarely paper birch seedlings.

SHRUBS, OCCASIONAL TO RARE

| | |
|---|---|
| *Alnus crispa* | *Rosa acicularis* |
| *Cornus canadensis* | *Salix arbusculoides* |
| *Elaeagnus commutata* | *S. setchelliana* |
| *Ledum palustre* ssp. *groenlandicum* | *Shepherdia canadensis* |
| *Potentilla fruticosa* | *Viburnum edule* |

Grasses appear to be rare, the only one encountered being *Calamagrostis purpurascens*. Grasslike plants are practically absent. Of the forbs, *Epilobium angustifolium* is perhaps the most abundant. Actually no species seems to be outstanding.

FORBS, OCCASIONAL TO RARE

*Aquilegia brevistyla*
*Artemisia arctica*
*Comandra livida*
*Equisetum arvense*
*Goodyera repens* var. *ophioides*
*Habenaria obtusata*
*Hedysarum alpinum* ssp. *americanum*
*H. mackenzii*
*Mertensia paniculata*
*Oxytropis campestris* var. *varians*
*Pyrola asarifolia* var. *incarnata*
*P. secunda*

Mosses are not prominent in balsam poplar stands. Seldom does a species have a coverage of more than 5 percent.

MOSSES, OCCASIONAL TO RARE

*Bryum caespiticium*
*Ceratodon purpureus*
*Dicranum drummondii*
*D. fragilifolium*
*Ditrichum flexicaule*
*Drepanocladus uncinatus*
*Hypnum revolutum*
*Hylocomium splendens*
*Pleurozium schreberi*

Lichens are very poorly represented. Only occasionally are the following species encountered: *Peltigera canina* var. *rufescens*, *Stereocaulon paschale* var. *alpinum*, and *S. paschale* var. *alpinum* f. *gracilentum*. As the stands mature and as white spruce develops, *Peltigera aphthosa* var. *typica* and *P. membranacea* appear.

The successional position of the balsam poplar type is not entirely clear. Characteristically it develops on recently deposited bars along rivers but the permanence of the type is not known. On some areas white spruce is gradually attaining dominance and will eventually replace the balsam poplar. In other situations the poplar appears to be a self-perpetuating community without any clear trend toward replacement by spruce or other species. Perhaps balsam poplar may occupy flood plain areas indefinitely if they are subjected to periodic overflow with deposition of alluvium. Raup (*125*) regarded willows and alders as predecessors of balsam poplars on flood plains in the southwestern Mackenzie region. Pulling (*123*) viewed the root system of balsam poplar as more or less flexible but not adapted to soils as shallow as some of those in which white spruce can thrive.

Fires occur in the balsam poplar type but are not nearly as common as in other forest communities. Based on limited evidence, it may be said that following fires the type regenerates by means of root suckers, and, to a lesser extent, from seed. In this respect the species behaves in much the same way as aspen.

## *White Spruce Type*

The white spruce type is the climax forest community on upland areas in the interior of Alaska (fig. 18). It is widespread and is responsible, more than any other forest type, for the vegetational aspect of the landscape. The dark, almost black, forest mantle so characteristic of upland areas in the interior is white spruce. Only in regions that have escaped recent fires is the cover of spruce forest complete; commonly it is broken by more or less extensive areas of paper birch, aspen, or types transitional between these and pure spruce. Boundaries are usually very sharp, marking the edges of fires. These boundaries between white spruce forest and aspen or paper birch forest are a common feature and appear as distinct lines that may be seen for miles.

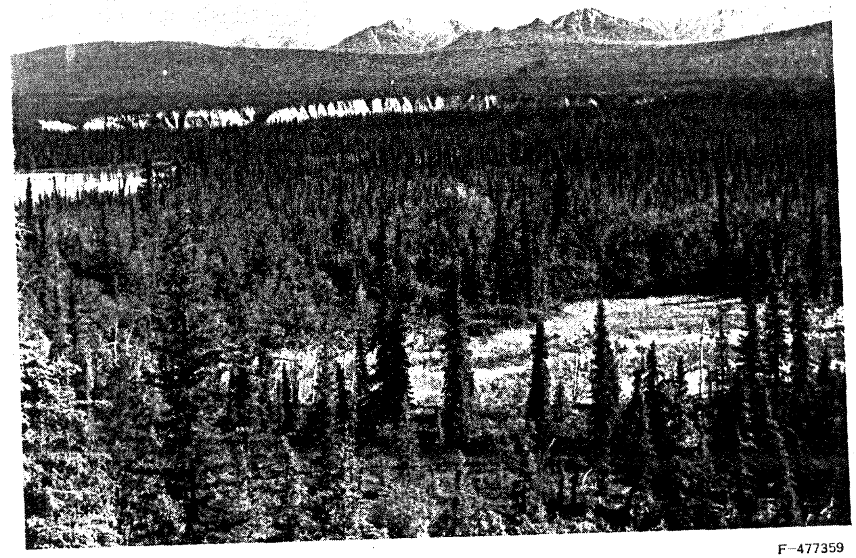

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FIGURE 18.—Climax white spruce forest along the Nelchina River, marked by eroding bluffs. Along Glenn Highway, at mile 143, looking eastward. 1951.

Generally the white spruce type is pure with only occasional representatives of black spruce, paper birch, and balsam poplar (table 8). The understory of small trees or large shrubs includes several species of willows and alder. Bebb willow is the most abundant member of the group, with 2,000 to 3,000 stems 1 inch in diameter, or larger, per acre in young stands, that is, up to 20 to 30 years old. With increase in stand age, the number of stems of Bebb willow decreases until they become very sparse in stands older than 160 years. Other willows attaining diameters of 1 inch, or more, at breast height include littletree willow, feltleaf willow, Scouler willow, and *Salix glauca* var. *aliceae*. Like the Bebb willow, these species are most abundant in young stands and decrease in numbers rapidly with increasing stand age, becoming scarce in stands older than about 160 years. The principal alder is Sitka alder; American green alder occurs occasionally. Unlike the willows, the alder is most common in the older stands, being scarce in forests having an age of less than about 120 years.

Initial densities are commonly high, with 2,000 to 3,000 stems 1 inch and larger in diameter per acre in stands from 20 to 25 years of age. The total number of stems per acre decreases with increasing age, but even at 160 to 180 years there are usually 300 to 500 per acre. In stands around 160 to 180 years of age, 100 to 150 trees per acre have diameters of 10 inches or more.

TABLE 8.—*Composition of white spruce stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up: Trees per acre | Diameter 2 inches and up: Basal area | Diameter 5 inches and up: Trees per acre | Diameter 5 inches and up: Basal area | Diameter 10 inches and up: Trees per acre | Diameter 10 inches and up: Basal area |
|---|---|---|---|---|---|---|---|
| | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| 20-year-old stand, P51-17: | | | | | | | |
| White spruce | 3,060 | 120 | 2.6 | 0 | 0 | 0 | 0 |
| Bebb willow | 2,980 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 120 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Salix glauca* var. *aliceae* | 560 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35-year-old stand, P51-20: | | | | | | | |
| White spruce | 950 | 780 | 88.5 | 360 | 61.0 | 0 | 0 |
| Bebb willow | 1,390 | 190 | ([1]) | 0 | 0 | 0 | 0 |
| Littletree willow | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40-year-old stand, P50-24: | | | | | | | |
| White spruce | 830 | 570 | 75.3 | 240 | 62.7 | 30 | 17.5 |
| Bebb willow | 450 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 230 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55-year-old stand, P50-14: | | | | | | | |
| White spruce | 1,620 | 1,240 | 94.1 | 220 | 48.8 | 20 | 10.9 |
| Bebb willow | 490 | 180 | ([1]) | 0 | 0 | 0 | 0 |
| 75-year-old stand, P51-18: | | | | | | | |
| White spruce | 3,040 | 2,400 | 170.7 | 400 | 73.6 | 0 | 0 |
| Bebb willow | 20 | 20 | ([1]) | 0 | 0 | 0 | 0 |
| 105-year-old stand, P51-31, white spruce | 2,210 | 2,150 | 224.9 | 1,030 | 165.3 | 0 | 0 |
| 120-year-old stands: | | | | | | | |
| P50-10, white spruce | 920 | 850 | 140.4 | 430 | 118.6 | 30 | 16.4 |
| P50-18: | | | | | | | |
| White spruce | 1,090 | 1,030 | 353.2 | 730 | 337.4 | 300 | 220.8 |
| Balsam poplar | 20 | 20 | 8.9 | 20 | 8.9 | 10 | 5.5 |
| 125-year-old stand, P50-11: | | | | | | | |
| White spruce | 220 | 220 | 79.5 | 160 | 76.4 | 70 | 50.1 |
| Black spruce | 190 | 190 | 38.4 | 150 | 35.7 | 0 | 0 |
| Alaska paper birch | 30 | 30 | 11.5 | 30 | 11.5 | 0 | 0 |
| American green alder | 60 | 10 | ([1]) | 0 | 0 | 0 | 0 |
| 130-year-old stand, P51-12: | | | | | | | |
| White spruce | 280 | 250 | 171.7 | 250 | 171.7 | 130 | 131.8 |
| Bebb willow | 330 | 100 | ([1]) | 10 | ([1]) | 0 | 0 |
| Littletree willow | 150 | 30 | ([1]) | 0 | 0 | 0 | 0 |
| 135-year-old stand, P51-33, white spruce | 1,530 | 1,410 | 183.9 | 610 | 141.0 | 40 | 23.0 |
| 140-year-old stand, P51-34, white spruce | 200 | 200 | 85.3 | 175 | 83.5 | 65 | 52.6 |
| 150-year-old stands: | | | | | | | |
| P51-16: | | | | | | | |
| White spruce | 200 | 160 | 98.6 | 110 | 97.3 | 60 | 79.7 |
| Bebb willow | 180 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Salix glauca* var. *aliceae* | 1,240 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 90 | 20 | ([1]) | 0 | 0 | 0 | 0 |
| P51-26: | | | | | | | |
| White spruce | 385 | 335 | 119.7 | 255 | 116.5 | 90 | 68.2 |
| Alaska paper birch | 55 | 25 | 1.8 | 5 | .7 | 0 | 0 |
| Black spruce | 15 | 15 | 5.7 | 15 | 5.7 | 0 | 0 |
| Sitka alder | 110 | 15 | ([1]) | 0 | 0 | 0 | 0 |
| Bebb willow | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160-year-old stand, P51-19: | | | | | | | |
| White spruce | 340 | 330 | 69.0 | 210 | 62.2 | 30 | 18.8 |
| Black spruce | 880 | 360 | 47.4 | 200 | 39.3 | 0 | 0 |
| Bebb willow | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 90 | 10 | ([1]) | 0 | 0 | 0 | 0 |
| *Salix glauca* var. *aliceae* | 90 | 0 | 0 | 0 | 0 | 0 | 0 |
| 165-year-old stand, P50-3: | | | | | | | |
| White spruce | 520 | 510 | 159.0 | 350 | 147.0 | 130 | 18.1 |
| Kenai paper birch | 80 | 80 | 22.2 | 80 | 22.2 | 0 | 0 |
| 170-year-old stands: | | | | | | | |
| P49-3: | | | | | | | |
| White spruce | 230 | 230 | 192.4 | 230 | 192.4 | 170 | 171.0 |
| Kenai paper birch | 50 | 50 | 34.9 | 50 | 34.9 | 50 | 34.9 |
| P50-23: | | | | | | | |
| White spruce | 390 | 360 | 121.2 | 270 | 114.5 | 60 | 50.4 |
| Balsam poplar | 30 | 30 | 6.3 | 20 | 5.5 | 0 | 0 |
| Feltleaf willow | 90 | 0 | 0 | 0 | 0 | 0 | 0 |
| Littletree willow | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| 175-year-old stand, P49-2: | | | | | | | |
| White spruce | 290 | 290 | 195.3 | 270 | 193.9 | 210 | 177.1 |
| Kenai paper birch | 40 | 40 | 25.4 | 40 | 25.4 | 30 | 22.7 |



TABLE 8.—*Composition of white spruce stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*—Continued

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up: Trees per acre | Diameter 2 inches and up: Basal area | Diameter 5 inches and up: Trees per acre | Diameter 5 inches and up: Basal area | Diameter 10 inches and up: Trees per acre | Diameter 10 inches and up: Basal area |
|---|---|---|---|---|---|---|---|
| 180-year-old stands: | | | | | | | |
| P49-10: | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| White spruce | 440 | 420 | 165.4 | 300 | 159.9 | 150 | 113.7 |
| Kenai paper birch | 40 | 40 | 21.0 | 40 | 21.0 | 20 | 16.1 |
| Sitka alder | 500 | 170 | ([1]) | 0 | 0 | 0 | 0 |
| Scouler willow | 20 | 20 | ([1]) | 0 | 0 | 0 | 0 |
| Quaking aspen | 10 | 10 | .2 | 0 | 0 | 0 | 0 |
| P50-16, white spruce | 570 | 550 | 183.5 | 360 | 174.9 | 180 | 126.1 |
| 185-year-old stands: | | | | | | | |
| P49-1: | | | | | | | |
| White spruce | 290 | 290 | 166.7 | 270 | 165.3 | 140 | 120.0 |
| Kenai paper birch | 50 | 50 | 23.9 | 50 | 23.9 | 30 | 17.5 |
| Black cottonwood | 20 | 20 | 28.4 | 20 | 28.4 | 20 | 28.4 |
| P49-4: | | | | | | | |
| White spruce | 260 | 260 | 162.3 | 240 | 161.0 | 140 | 129.5 |
| Kenai paper birch | 20 | 20 | 12.3 | 20 | 12.3 | 10 | 7.9 |
| P49-9: | | | | | | | |
| White spruce | 520 | 510 | 194.5 | 400 | 188.4 | 170 | 120.5 |
| Kenai paper birch | 40 | 40 | 16.0 | 40 | 16.0 | 20 | 12.1 |
| 190-year-old stands: | | | | | | | |
| P49-11: | | | | | | | |
| White spruce | 680 | 670 | 202.6 | 460 | 192.6 | 140 | 100.9 |
| Kenai paper birch | 40 | 40 | 19.0 | 40 | 19.0 | 20 | 12.1 |
| Sitka alder | 30 | 10 | ([1]) | 0 | 0 | 0 | 0 |
| P49-12: | | | | | | | |
| White spruce | 210 | 210 | 134.1 | 180 | 132.2 | 120 | 116.3 |
| Kenai paper birch | 40 | 40 | 43.6 | 40 | 43.6 | 40 | 43.6 |
| Sitka alder | 50 | 40 | ([1]) | 0 | 0 | 0 | 0 |
| 200-year-old stands: | | | | | | | |
| P51-11: | | | | | | | |
| White spruce | 54 | 42 | 14.4 | 30 | 13.8 | 12 | 8.9 |
| Black spruce | 42 | 18 | .5 | 0 | 0 | 0 | 0 |
| P51-24, white spruce | 860 | 840 | 202.5 | 640 | 191.6 | 70 | 41.8 |
| 215-year-old stands: | | | | | | | |
| P49-5, white spruce | 240 | 240 | 192.6 | 200 | 190.5 | 170 | 181.7 |
| P49-14: | | | | | | | |
| White spruce | 300 | 300 | 175.7 | 240 | 172.0 | 140 | 140.6 |
| Kenai paper birch | 10 | 10 | 14.0 | 10 | 14.0 | 10 | 14.0 |
| Sitka alder | 380 | 250 | ([1]) | 0 | 0 | 0 | 0 |
| 220-year-old stands: | | | | | | | |
| P49-7: | | | | | | | |
| White spruce | 240 | 240 | 171.2 | 240 | 171.2 | 200 | 156.2 |
| Kenai paper birch | 30 | 30 | 10.6 | 10 | 9.2 | 10 | 9.2 |
| P50-9: | | | | | | | |
| White spruce | 770 | 730 | 64.4 | 180 | 33.9 | 0 | 0 |
| American green alder | 1,190 | 80 | ([1]) | 0 | 0 | 0 | 0 |
| 225-year-old stand, P49-13: | | | | | | | |
| White spruce | 410 | 410 | 226.0 | 370 | 223.3 | 180 | 157.5 |
| Kenai paper birch | 10 | 10 | 4.4 | 10 | 4.4 | 0 | 0 |
| Sitka alder | 230 | 110 | ([1]) | 0 | 0 | 0 | 0 |
| 230-year-old stands: | | | | | | | |
| P49-8: | | | | | | | |
| White spruce | 190 | 190 | 125.3 | 170 | 124.6 | 120 | 110.9 |
| Kenai paper birch | 20 | 20 | 6.2 | 20 | 6.2 | 0 | 0 |
| P49-15: | | | | | | | |
| White spruce | 290 | 290 | 194.2 | 280 | 194.0 | 190 | 169.6 |
| Kenai paper birch | 10 | 10 | 6.6 | 10 | 6.6 | 10 | 6.6 |
| P50-15: | | | | | | | |
| White spruce | 270 | 270 | 132.6 | 240 | 130.8 | 120 | 98.0 |
| Black spruce | 245 | 235 | 26.1 | 120 | 19.3 | 0 | 0 |
| Sitka alder | 310 | 70 | ([1]) | 0 | 0 | 0 | 0 |
| P50-5, white spruce | 600 | 580 | 210.6 | 440 | 203.1 | 140 | 113.9 |
| 260-year-old stand, P49-6: | | | | | | | |
| White spruce | 370 | 370 | 225.4 | 270 | 221.2 | 170 | 195.9 |
| Kenai paper birch | 50 | 50 | 11.5 | 40 | 11.0 | 0 | 0 |
| 360-year-old stand, P51-21: | | | | | | | |
| White spruce | 70 | 70 | 33.4 | 70 | 33.4 | 20 | 16.1 |
| Black spruce | 700 | 380 | 14.6 | 10 | 1.4 | 0 | 0 |

[1] Basal area not determined.

Forest-canopy density tends to decrease with increasing stand age; greatest density is usually encountered in forests less than 160 years of age. In the subordinate vegetation the greatest density of cover is found in the ground layer (0 to 2 inches) where values of 75 to 100 percent are usual. Lowest densities are found in the layers 1 to 2.5 feet and 2.5 to 6 feet above the ground where density is usually less than 10 percent.

Maximum heights in the oldest spruce stands seldom exceed 85 to 100 feet and maximum diameters are seldom more than 20 to 24 inches. Average values are considerably less.

White spruce forests may be even aged or uneven aged, depending on their history. Stands that seeded in burned areas are usually even aged whereas those that originated as a result of entry of spruce into other forest types, principally paper birch or quaking aspen, more commonly are uneven aged. In all cases the number of age classes increases with increasing stand age. Garman (*47*), working in central British Columbia, wrote as follows: "The open nature of the forest often found in the first generation after fire indicates that eventually there will be an uneven aged forest, as a result of the filling in process which will follow the elimination of aspen and birch by spruce, but as the stands become older the age differences will become less obvious."

Tree reproduction in most spruce stands was predominantly white spruce. On the average there were about 3,700 seedlings per acre, with a frequency of occurrence of approximately 50 percent on the plots studied. Birch averaged about 600 seedlings per acre, with a frequency of 40 percent. Spruce was the only tree species that reproduced itself in numbers. Most of the birch seedlings and sprouts died after a few years unless they were located in openings in the forest canopy.

In addition to the willows already mentioned (Bebb willow, *Salix glauca* var. *aliceae*, feltleaf willow, littleleaf willow, smooth littleleaf willow, and Scouler willow) several other species were encountered occasionally: Barclay willow, including var. *rotundifolia*, grayleaf willow, *S. glauca* var. *acutifolia*, blueberry willow, park willow, netleaf willow, Richardson willow, and Walpole willow.

### Most Abundant Shrubs, Exclusive of Willows

*Arctostaphylos alpina* ssp. *rubra*
*Cornus canadensis*
*Empetrum nigrum*
*Ribes triste*
*Rosa acicularis*
*Rubus pedatus* (in stands more than 160 years of age)
*Vaccinium vitis-idaea*
*Viburnum edule*

These species have relatively high frequencies but relatively low density of cover. An exception is *Vaccinium vitis-idaea*, which commonly has coverage values in excess of 25 percent.

### Common Shrubs

*Ledum palustre* ssp. *decumbens*
*Shepherdia canadensis*
*Vaccinium uliginosum*



### Occasional to Rare Shrubs

*Arctostaphylos uva-ursi*
*Betula glandulosa*
*Cassiope tetragona*
*Menziesia ferruginea*
*Potentilla fruticosa*
*Rubus alaskensis*
*R. chamaemorus*
*Vaccinium cespitosum*

*Menziesia ferruginea* tends to occur only in the oldest stands.

Grasses are scarce in spruce stands less than about 120 years old. In general they are less well represented in spruce forests than in stands representing earlier stages of succession. *Calamagrostis canadensis* is by far the most prominent species, occurring widely but sparsely. Density of cover is usually less than 5 percent.

### Grasses, Occasional To Rare

*Agropyron latiglume*
*Agrostis scabra*
*Arctagrostis latifolia*
*Bromus arcticus*
*Calamagrostis purpurascens*
*Festuca altaica*
*F. ovina*
*F. rubra* var. *lanuginosa*
*Phleum alpinum*
*Poa glauca*
*P. pratensis*
*Trisetum spicatum*

*Carex concinna* is frequently encountered in the white spruce forest.

### Grasslike Plants, Occasional to Rare

*Carex bigelowii*
*C. capillaris*
*C. disperma*
*C. media*
*C. scirpoidea*
*C. vaginata*
*Eriophorum vaginatum*
*Juncus castaneus*
*Luzula parviflora*

They are more often encountered in old than in young stands.

Many species of forbs are found in the white spruce type.

### Forbs, Most Abundant

*Comandra livida*
*Dryopteris disjuncta* (in stands less than 160 years of age)
*Epilobium angustifolium*
*Equisetum arvense* (in stands more than 160 years of age)
*E. pratense*
*E. scirpoides*
*Goodyera repens* var. *ophioides*
*Linnaea borealis* var. *americana*
*Listera cordata* (in stands more than 160 years of age)
*Lycopodium annotinum* (in stands more than 160 years of age)
*Mertensia paniculata*
*Pyrola asarifolia* var. *incarnata*
*P. secunda*
*P. virens* (in middle-aged stands)
*Trientalis europaea* ssp. *arctica*

### Forbs, Occasional to Rare

*Achillea borealis*
*Aconitum delphinifolium*
*Androsace lehmanniana*
*Arenaria lateriflora*
*Artemisia arctica*
*Aster sibericus*
*Astragalus alpinus*
*Boykinia richardsonii*

FORBS, OCCASIONAL TO RARE—Continued

*Castilleja pallida* ssp. *mexiae*
*Dryopteris austriaca* (in old stands)
*Equisetum sylvaticum*
*Erigeron purpuratus*
*Galium boreale*
*Gentiana propinqua*
*Hedysarum mackenzii*
*Lupinus arcticus*
*L. nootkatensis*
*Moneses uniflora*
*Orchis rotundifolia*
*Oxytropis campestris* var. *varians*
*Parnassia kotzebuei*
*Pedicularis labradorica*
*Petasites frigidus*
*Pyrola grandiflora*
*Rumex arcticus*
*Sanguisorba stipulata*
*Saussurea angustifolia*
*Senecio atropurpureus* ssp. *frigidus*
*S. integerrimus*
*Solidago multiradiata*
*Stellaria longipes*
*Streptopus amplexifolius*
*Tofieldia coccinea*
*T. pusilla*
*Valeriana capitata*
*Zigadenus elegans*

Mosses are characteristic of the ground cover vegetation in the white spruce type. Two species are especially prominent in stands over 50 years of age; these are *Hylocomium splendens* and *Pleurozium schreberi*. Commonly one or both of these species has a coverage of 25 to 100 percent. *Dicranum fuscescens* is also an abundant species, usually appearing in stands between 50 and 200 years of age. *Drepanocladus uncinatus* is most prominent in stands less than 120 years of age, and *Polytrichum commune* and *P. strictum* occur most abundantly in stands more than 150 years of age.

MOSSES, COMMON

*Aulacomnium palustre*
*Brachythecium albicans*
*Ptilium crista-castrensis*
*Mnium affine*
*Rhytidium rugosum*
*Tomenthypnum nitens*

MOSSES, OCCASIONAL TO RARE

*Brachythecium salebrosum*
*Bryum caespiticium*
*B. cuspidatum*
*Calliergon stramineum*
*Camptothecium lutescens*
*Ceratodon purpureus*
*Dicranella grevilleana*
*Dicranum bergeri*
*D. elongatum*
*D. fragilifolium*
*D. muhlenbeckii*
*Ditrichum flexicaule*
*Eurhynchium substrigosum*
*Hypnum imponens*
*H. lindbergii*
*Leptobryum pyriforme*
*Meesia uliginosa*
*Oncophorus wahlenbergii*
*Pohlia nutans*
*Polytrichum juniperinum*
*P. strictum*
*Rhytidiadelphus triquetrus*
*Sphagnum capillaceum*
*S. girgensohnii*
*Tetraplodon mnioides*
*Thuidium delicatulum*
*Timmia austriaca*
*Tortella fragilis*

The liverwort *Ptilidium ciliare* is encountered occasionally.

The most abundant lichens in spruce forests are *Peltigera aphthosa* var. *typica*, *P. aphthosa* var. *variolosa*, and *P. membranacea*. They occur on the majority of plots.

LICHENS, COMMON

*Cetraria cucullata*
*C. nivalis*
*Cladonia amaurocraea* f. *celotea*
*C. coccifera*
*C. cornuta* f. *cylindrica*
*C. gracilis* var. *dilatata*
*C. gracilis* var. *elongata*
*C. mitis*
*C. rangiferina*
*C. sylvatica*
*Stereocaulon paschale*
*S. tomentosum*

LICHENS, OCCASIONAL TO RARE

*Cetraria hiascens*
*C. islandica*
*C. juniperina*
*C. tilesii*
*Cladonia alpestris*
*C. amaurocraea* f. *fasciculata*
*C. amaurocraea* f. *oxyceras*
*C. cariosa*
*C. cariosa* f. *corticata*
*C. cariosa* f. *squamulosa*
*C. chlorophaea* f. *simplex*
*C. cornuta* f. *scyphosa*
*C. deformis*
*C. degenerans* f. *cladomorpha*
*C. degenerans* f. *euphorea*
*C. degenerans* f. *gracilescens*
*C. furcata* var. *racemosa* f. *corymbosa*
*C. gracilis* var. *chordalis*
*C. gracilis* var. *chordalis* f. *platydactyla*
*C. multiformis* f. *finkii*
*C. pseudorangiformis*
*C. pyxidata* var. *neglecta*
*C. rangiferina* f. *stygia*
*C. scabruiscula*
*C. scabruiscula* f. *surrecta*
*C. uncialis*
*C. verticillata* f. *evoluta*
*Dactylina arctica*
*Diploschistes scruposus*
*Dufourea madreporiformis*
*Nephroma arcticum*
*N. expallidum*
*Ochrolechia frigida*
*Peltigera canina*
*P. canina* var. *rufescens*
*P. malacea*
*Stereocaulon paschale* var. *alpinum* f. *gracilentum*

In the older stands the beard lichens *Usnea comosa* ssp. *comosa*, *Alectoria jubata*, and *Lobaria pulmonaria* are commonly seen. Evidently about 40 years must elapse after a fire before the so-called reindeer lichens reappear. In general, species of *Cladonia* tend to be more common in stands less than 170 years old than in stands past that age. Lichens are, for the most part, plants that flourish in relatively open habitats. Lynge (*84*) mentioned the lack of lichens in dense *Picea excelsa* forests in Norway.

Essentially pure stands of white spruce are regarded as the climax type on reasonably well-drained soils in the Alaska interior (fig. 19). This tree has all the attributes of a species characteristic of terminal, self-perpetuating (climax) communities. Various stages of succession to this climax may be observed.

MacKenzie recorded what is probably the earliest observation of forest succession following fires in northwestern America. On his journey down the river which now bears his name he made the following entry in his journal (*87, p. 24*) in June 1789:

> The current is very strong, and the banks are of an equal height on both sides, consisting of a yellow clay, mixed with small stones; they are covered with large quantities of burned wood, lying on

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FIGURE 19.—A 150-year-old climax white spruce stand on a southwest slope. The dominants are 9 to 16 inches d. b. h. and 70 to 85 feet tall.

the ground, and young poplar trees, that have sprung up since the fire that destroyed the larger wood. It is a very curious and extraordinary circumstance, that land covered with spruce pine, and white birch, when laid waste by fire, should subsequently produce nothing but poplars, where none of that species of tree were previously to be found.

The curious and extraordinary circumstance which MacKenzie so accurately observed was an example of forest succession now recognized as most common. In 1889 Bell (*11*), also writing of conditions in Canada, was even more explicit in his statement of vegetational changes occurring following fires. He wrote:

> The following is the course of events after a fire has run through a tract of the full-grown northern coniferous forest, the fires always occurring during the driest part of the summer: In the next spring weeds and bushes (raspberry, huckleberry, red elder, etc.) begin to spring up and partly occupy the blackened ground. These increase for two or three years, and as they die out are gradually replaced by the poplars, white birch, pigeon cherry, willows, etc., with a few conifers. The willows and pigeon cherry are short lived. The poplars attain their full size and decay in about seventy years, and the white birch shows signs of old age in less than one hundred years. In the meantime the proportion of conifers is constantly increasing from new individuals springing up, so that by the time the deciduous trees have died out the ground has become completely occupied by the former.

Chambers (*31*), in discussing the work of Dr. George M. Dawson in the MacKenzie Basin, wrote as follows:

> In its primitive state, the surface was probably covered with a dense and heavy growth of coniferous trees, principally the spruce (*Picea engelmanni* and *P. alba*), but with scrub pine (*Pinus contorta*) in some localities, and interspersed with aspen and cottonwood. These forests having been destroyed by fire, a second growth, chiefly of aspen, but with much birch in some places, and almost everywhere a certain portion of coniferous trees—chiefly spruce—had taken its place. The aspen being a short-lived tree, while the spruce reached a great age and size, the natural course of events, if undisturbed, would lead to the reestablishment of the old spruce forests.

From descriptions of Nuttonson (*103*) and others, it may be concluded that forest succession in Siberia is similar to that in northern Canada and Alaska.

Single light surface fires in a white spruce forest do not result in complete destruction of the stand. Openings are created, however, and birch, and occasionally willows and aspen, appear. Changes in forest composition thus induced are relatively small. Single light surface fires usually do not result in a complete change in the forest type. Saari (*133*) in Finland showed that the average damage per unit area of forest burned, or the absolute destructiveness of fires, is greatest in the spruce, because it is damaged very easily. He found, as might be expected, that complete destruction of the main stand was most common in young forests and, conversely, that in some instances the main forest stand was undamaged.

Single severe fires generally result in complete destruction of the existing stands and replacement by communities of sub-climax species. The composition of the new stand is primarily dependent on the seed sources adjacent to the burn. If the area burned was extensive and if all white spruce seed trees are killed, the reproduction will consist largely of aspen, paper birch, and cottonwood. These species are widely disseminated by wind. If aspen trees were present in the stand destroyed, the species will be heavily represented in the new stand because aspen reproduces abundantly by root suckers. Holman and Parker (*63*) regard light spring or early summer fires in the Prairie Provinces of Canada as less likely to result in good spruce reproduction than severe late summer or early fall fires. They stated:

> Where fire or logging has occurred and not removed moss, duff, or debris to a compact moisture-retaining seedbed no reproduction has occurred [in Alberta], even though sufficient seed trees have been left. Where fire or logging has occurred and has resulted in the removal of moss, duff and debris, reproduction has

always occurred, if an adequate seed supply was available. In late summer and fall fires the seed supply may be in the form of cones on the trees that have been killed, but even this appears in most cases to be adequate for the purpose of restocking.

Black spruce may be strongly represented in the reproduction following fire in white spruce on upland areas. This migration of black spruce from its normal lowland habitat to fireswept uplands has already been mentioned. Occasionally reproduction of essentially pure white spruce may become established following fires in the climax type. This occurs most frequently when the burned areas are relatively small and are surrounded by, or are adjacent to, living trees of seed-bearing age.

Shortly after a severe fire has swept through a spruce forest, the dead trees begin to fall, creating a tangle of flammable material that is difficult to penetrate. The result is that the fire hazard is greatly increased. Fire-killed snags usually do not remain standing as long in the North as in regions to the south. The trees are generally shallow rooted with most of the roots in the forest floor and uppermost horizons of mineral soil. Fires burn most intensely and deeply around the tree bases with the result that the prop roots are burned off. Following a fire the hazard due to fallen snags gradually increases for 5 to 10 years and then slowly decreases during the following 10 to 20 years. The rate of decay varies with aspect and ground conditions, as well as with the size of the material. In general, however, snags do not constitute much of a hazard 20 to 30 years after a fire. Much of the timber killed by the great fire on the Kenai Peninsula in 1947 is already on the ground. There the fire hazard will remain abnormally high for many years.

The frequency of burning has an important bearing on the composition of the plant communities that develop. Areas that once supported white spruce have become treeless as a result of repeated fires. A dense cover of fireweed and grass (chiefly *Epilobium angustifolium* and *Calamagrostis canadensis*) now occupies areas that previously supported forests. The fireweed and grass, together with other herbaceous plants, often produce an unbelievably rank growth, frequently attaining a height of 5 to 6 feet. This presents an effective barrier to the re-entry of tree seedlings. In the spring, before new growth has started, the mat of litter representing the previous year's growth may be 6 or more inches in thickness. Beneath this mat may be found a layer of humus 8 or more inches thick, resting on mineral soil. The mineral soil in such situations sometimes exhibits the leached $A_2$ horizon of a podzol profile developed under forest cover. Fireweed-grass communities when well developed appear to be relatively stable; natural reconversion to forest, where this occurs, evidently requires 100 to 200 years. Pohle (*119*), in his studies on the Kanin Peninsula in northern Russia, found that openings created in the forest by fires supported a luxuriant growth of herbaceous plants. He pointed out that this growth may develop so early in the spring that its density prevents the development of tree seedlings.

Another change in vegetation type is from a forest to a shrubby cover of dwarf birch and willows. This community is evidently not as stable as the fireweed-grass type. Re-entry of tree species, especially spruce, seems to occur more readily.

The effects of fire on forest vegetation are most severe on the poorest sites. In general, the change in vegetation is most profound and subsequent recovery most slow on steep slopes having southerly or westerly exposures and on rocky or ledgy areas where mineral soil is shallow or nearly lacking. Forest recovery from fire is dangerously slow at the upper altitudinal and latitudinal limits of forest growth.

Pohle (*120*) investigated the tree and forest limits in northern Russia. He stated that if the forest at its northernmost limits is opened up, tundra vegetation, which characteristically has high light requirements, may enter and flourish. The tundra vegetation can be held in check only if immediately following the disturbance to the forest there is a good tree-seed year, that is, only if a new stand of young trees again shades the ground. Prompt return of tree growth in such areas, however, is probably the exception rather than the rule because near the limits of tree growth seed years occur very infrequently. Pohle observed that in the majority of cases the tundra vegetation becomes established as a relatively permanent community. Hustich (*64*) issued a warning relative to the care needed in managing the northern forests in Labrador, and referred to "the warnings expressed by North-European forest scientists against an exploitation of the northernmost forests, just because of their few seed years and slow regrowth."

Fires in the northern forest have sometimes exercised a beneficial effect in providing conditions for establishment of rapidly growing, healthy forest stands. Gilmore (*48*) stated that burned areas in Newfoundland support better stands of spruce than do areas of virgin timber where there has been no fire for a very long time. He found the percentage of spruce higher and the rate of growth better on burned areas than where fires had not occurred. Rubner (*132*), in discussing forest conditions in Finland, remarked that those familiar with northern forest conditions recognized that fires may have favorable effects; he stated that the best spruce and pine stands occur on former burns. After detailing the effects of fire in Scandinavia, Tamm (*151*) wrote as follows: "The forest fire with its consequences has thus in north Sweden usually been nature's own and very satisfactory method of regeneration, especially in respect of the Vaccinium forests but also of other forest associations."

Recognition of possible past benefits of fire, whether in the Coast Douglas-fir region or in the white spruce forests of the high North, does not mean that uncontrolled forest fires can now be condoned. Fire is a poor master but, under control, may be a good servant.

## *Black Spruce Type*

Black spruce usually occurs in situations where drainage is poor and permafrost is close to the soil surface. Stands of this species are generally encountered in relatively flat valley bottoms, on flat to gently rolling land, and on cold slopes having a north exposure. Raup (*124*), working along the Alaska Highway, thought that on the more or less level terrain there was a fair coincidence between the occurrence of black spruce and soils derived from clays or clayey glacial tills. The species may also invade upland areas normally occupied by white spruce (fig. 20). This occurs following fires when a

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FIGURE 20.—A 55-year-old stand of black spruce. Dominants are 2 to 4 inches d. b. h. and about 15 feet tall. Snags are relicts of 2 fire-killed stands. The last fire killed a pole stand of black spruce and an earlier fire killed a stand of white spruce containing trees 10 to 12 inches d. b. h. This is an example of black spruce replacing white spruce, following repeated fires.

source of black spruce seed is available and white spruce seed is lacking. Black spruce is regarded as a fire species because it reproduces abundantly following fires, mostly from seed stored in the persistent cones.

Tree composition in the black spruce type is shown in table 9. Characteristically, black spruce forms pure stands. Normally it grows in wet, poorly drained habitats and competition from other tree species is slight. Perhaps equally important in accounting for the pure stands is the generally abundant supply of black spruce seed. Less important is the ability of black spruce to reproduce vegetatively by layering. Occasionally one encounters individuals of white spruce and paper birch, but they form a very minor component in most black spruce stands. Grayleaf willow and littletree willow occasionally attain a diameter of 1 inch or more and a height exceeding 6 feet but their occurrence is limited.

Stand densities are very high in young black spruce stands; there often are 5,000 stems 1 inch or more in diameter per acre in stands 30 years of age and older. Even in stands 100 years of age and older, there may be a total of 2,000 to 3,000 stems per acre with 200 to 300 trees 5 or more inches in diameter.

Forest-canopy density appears to decrease slightly after stands attain an age of about 200 years; in stands up to 100 to 150 years old, crown density is high. In the subordinate vegetation, greatest density of coverage is seen in the ground layer (0 to 2 inches) where densities approaching 100 percent are usual. Lowest densities are



encountered in the layers 1 to 2.5 feet and 2.5 to 6 feet where coverage is usually less than 5 percent.

Maximum heights in mature black spruce forests usually do not exceed 45 feet and maximum diameters are seldom more than 8 to 9 inches. Young black spruce stands, originating following fires, are usually even aged. In stands past 100 years of age, however, they tend to become increasingly more uneven aged.

TABLE 9.—*Composition of black spruce stands in interior Alaska: Number of trees and basal area per acre, by stand age, species, and diameter (breast high) group*

| Stand age, plot number, and species | Trees per acre 1 inch and up in diameter | Diameter 2 inches and up | | Diameter 5 inches and up [1] | |
|---|---|---|---|---|---|
| | | Trees per acre | Basal area | Trees per acre | Basal area |
| | *No.* | *No.* | *Sq. ft.* | *No.* | *Sq. ft.* |
| 30-year-old stands: | | | | | |
| P49-28, black spruce | 4,900 | 2,110 | 82.9 | 40 | 6.7 |
| P51-29: | | | | | |
| Black spruce | 4,640 | 440 | 11.3 | 0 | 0 |
| White spruce | 20 | 20 | 1.0 | 0 | 0 |
| 55-year-old stand, T50-5: | | | | | |
| Black spruce | 1,300 | 725 | 20.8 | 0 | 0 |
| White spruce | 25 | 25 | 1.2 | 0 | 0 |
| 80-year-old stand, P50-25: | | | | | |
| Black spruce | 780 | 690 | 61.3 | 200 | 37.1 |
| White spruce | 20 | 20 | 3.5 | 10 | 2.7 |
| Grayleaf willow | 730 | 0 | 0 | 0 | 0 |
| Littletree willow | 40 | 0 | 0 | 0 | 0 |
| 85-year-old stand, P51-23: | | | | | |
| Black spruce | 5,960 | 3,610 | 142.1 | 20 | 2.7 |
| White spruce | 20 | 20 | 2.7 | 20 | 2.7 |
| 100-year-old stand, P51-28: | | | | | |
| Black spruce | 2,910 | 1,810 | 128.6 | 300 | 51.2 |
| Alaska paper birch | 20 | 20 | 1.0 | 0 | 0 |
| 200-year-old stand, P50-19, black spruce | 1,960 | 1,825 | 122.4 | 195 | 28.7 |

[1] No trees reached 10 inches in diameter.

Reproduction is confined to black spruce. Practically all stands have reproduction established, with an average of around 4,100 seedlings and layers per acre. Willows of all kinds (less than 6 feet in height) average about 4,700 stems per acre. No one species is predominant, except locally. The following species are represented: Littletree willow, smooth Bebb willow, grayleaf willow, its var. *acutifolia*, and var. *aliceae*, blueberry willow, diamondleaf willow, netleaf willow, and Scouler willow.

### MOST ABUNDANT SHRUBS, OTHER THAN WILLOWS

| | |
|---|---|
| *Arctostaphylos alpina* ssp. *rubra* | *Rosa acicularis* |
| *Empetrum nigrum* | *Vaccinium uliginosum* |
| *Ledum palustre* ssp. *groenlandicum* | *V. vitis-idaea* |

### SHRUBS, OCCASIONAL TO RARE

| | |
|---|---|
| *Betula glandulosa* | *Menziesia ferruginea* |
| *B. nana* ssp. *exilis* | *Oxycoccus microcarpus* |
| *Cassiope tetragona* | *Potentilla fruticosa* |
| *Cornus canadensis* | *Rhododendron lapponicum* |
| *Ledum palustre* ssp. *decumbens* | *Vaccinium cespitosum* |

Grasses are unimportant in the black spruce type. *Arctagrostis latifolia* is perhaps the most frequently encountered species. Occasional to rare are *Calamagrostis canadensis*, *Festuca altaica*, and *Poa paucispicula*.

Of the grasslike plants, the sedges are occasionally encountered but are not at all common. *Carex lugens* perhaps is seen more frequently than any other species. *Carex canescens*, *C. vaginata*, *Eriophorum brachyantherum*, *E. vaginatum*, and *Luzula rufescens* are occasional to rare. The grasslike plants appear to be slightly more frequent in stands more than 60 years of age than in young stands.

The most abundant forbs in black spruce stands are *Equisetum scirpoides*, *Petasites frigidus*, and *Pyrola secunda*.

FORBS, OCCASIONAL TO RARE

*Astragalus alpinus*
*Chrysosplenium tetrandrum*
*Epilobium angustifolium*
*Equisetum arvense*
*Linnaea borealis* var. *americana*
*Mertensia paniculata*
*Pedicularis labradorica*
*Pyrola asarifolia* var. *incarnata*
*Rumex arcticus*
*Saussurea angustifolia*
*Saxifraga hieracifolia*
*Senecio integerrimus*

Mosses are a characteristic component of the vegetation in the black spruce forest. They often completely cover the surface of the forest floor. Most common is *Hylocomium splendens*.

MOSSES, LESS COMMON

*Aulacomnium palustre*
*Dicranum drummondii*
*Drepanocladus uncinatus*
*Pleurozium schreberi*
*Sphagnum rubellum*
*Tomenthypnum nitens*

Sphagnum mosses, practically lacking in other forest types, are characteristic of black spruce stands, especially in the older age classes.

MOSSES, OCCASIONAL TO RARE

*Aulacomnium turgidum*
*Dicranum elongatum*
*D. fuscescens*
*D. majus*
*D. strictum*
*Hypnum dieckii*
*Polytrichum commune*
*P. juniperinum*
*P. strictum*
*Sphagnum girgensohnii*
*S. plumulosum*

Although a considerable variety of lichens occur in the black spruce type, they usually do not occupy appreciable areas of the forest floor. Coverage is usually less than 5 percent.

LICHENS, MOST COMMON

*Cladonia coccifera*
*C. cornuta* f. *cylindrica*
*C. degenerans* f. *euphorea*
*C. gracilis* var. *dilatata*
*C. mitis*
*Peltigera aphthosa* var. *aphthosa*

LICHENS, OCCASIONAL TO RARE

*Cetraria cucullata*
*C. islandica*
*Cladonia alpestris*
*C. amaurocraea* f. *celotea*
*C. amaurocraea* f. *oxyceras*
*C. cenotea* f. *crossota*
*C. crispata* var. *infundibulifera*
*C. crispata* var. *virgata*
*C. deformis*
*C. degenerans* f. *cladomorpha*
*C. gonecha*
*C. rangiferina*
*C. rangiferina* f. *stygia*
*C. scabriuscula* f. *sublevis*
*C. sylvatica*
*C. uncialis*
*Dactylina arctica*
*Nephroma arcticum*
*Peltigera aphthosa* var. *variolosa*
*P. canina*
*P. canina* var. *rufescens*
*P. pulverulenta*

In the older stands, beard lichens such as *Alectoria jubata* and *Usnea comosa* ssp. *comosa* occur commonly on the trees.

Black spruce represents a physiographic climax on cold, poorly drained soils in the forested region of the Alaska interior. Here it represents an essentially stable, self-perpetuating community, reproducing itself by both seedling growth and layering. The type also occasionally occurs on moderately well-drained uplands where, as a result of fires, it has replaced white spruce. In these situations it must be regarded as a temporary fire type which will, in the course of time, give way to white spruce.

Fires in black spruce are often intense, completely killing the vegetation and consuming the forest-floor material. The high stand density and relatively low stature of the trees favor crown fires. The flammability is often increased by the presence of beard lichens (principally *Alectoria jubata* and *Usnea comosa* ssp. *comosa*) on the trees. These lichens are tinderlike when dry.

The black spruce type usually regenerates itself following fires. Millar (*97*) reported this tendency in Ontario, Canada. He found that, following fires, the stands were not radically different from the climax type. Repeated burning at short intervals may result in replacement of the black spruce by treeless communities such as sedge-rush-grass or low shrub. These may persist indefinitely because of the difficulty of establishment of spruce seedlings. In areas where the ground water is close to the surface, destruction of forest vegetation is known to result in a rise of the water table, producing swamp conditions (*22*, *55*, *164*).

## EFFECT OF FIRE ON SOILS

In a region such as the interior of Alaska, where forest fires each year burn over extensive areas, it is natural that questions should arise as to influence of fires on soils. The problem has attracted attention in almost every country in the world. Investigators in the Scandinavian countries and in the United States, particularly, have done much to improve our knowledge of the subject.

The interior of Alaska has many kinds of soil, how many no man knows. Soil classification and inventory in Alaska are in their infancy. The principal reports on Alaskan soils are specifically designated as being of a reconnaissance character (*12*, *13*) or of an

exploratory nature (*68*). Nevertheless, certain statements may be made on the basis of present scanty information.

In general the soils in the interior of Alaska are shallow, both in the sense of soil development and in a physiological sense; many are young. Under forest vegetation, soil temperatures are low, even above the frozen ground which, during August, may be encountered at depths of as little as 1 to 2 feet. This is especially true in dense spruce forests having a well-developed forest floor. The low temperatures inhibit chemical weathering of the soil material, reduce to a low level the activity of soil organisms, and unfavorably affect physiological processes in plant roots.

From the standpoint of mechanical composition, many, if not most, soils contain relatively little clay. This is probably a reflection of the slowness of chemical weathering and the youthfulness of the soils. Many of the soils possess upper layers with a high proportion of very fine sand and silt, fractions that appear to have been brought in by wind. The surface soil is often fluffy when dry; cohesion is weak, and aggregates, if present, tend to be small and soft. Weak platy aggregates are sometimes seen. Internal soil drainage, under natural conditions, is usually slow to poor. Frozen ground at shallow depths commonly produces, in effect, a perched water table. Some soils have developed over coarse gravelly or cobbly alluvium; these tend to be so excessively drained that natural vegetation such as quaking aspen and balsam poplar defoliates during the middle of the summer because of water shortage.

In the majority of forest soils in the interior there appears to be relatively little leaching due to low precipitation, and the depth to frozen ground is relatively shallow. Leaching seems to be greater in soils south of the Alaska Range than to the north. Well-developed podzols occur in many places on the Kenai Peninsula, in the Susitna Valley, and in the Copper River Valley. North of the Alaska Range, podzols are weak and encountered only occasionally.

The organic matter tends to be unincorporated with the mineral soil, resting on it as a mantle. Thickness of the unincorporated organic matter varies from 2 to 4 inches in birch, quaking aspen, and balsam poplar stands to 4 to 6 inches in spruce forests. Under old white spruce, and especially in black spruce, the layers of organic matter may be 12 inches thick. The general lack of incorporation of organic matter into the mineral soil appears to result from the scarcity of soil animals such as earthworms and large arthropods. In fact, no earthworms were found in undisturbed forest soils in the interior of Alaska.

The layers of unincorporated organic matter in undisturbed forests are moderately acid; pH values are often about 4.5 south of the Alaska Range. In sections where the precipitation is lower, values of around 6.0 have been found. An indication of the variation in Alaskan soils is found on an aspen-covered southerly slope near Sheep Mountain in the upper Matanuska Valley, where a gray or white zone of calcium carbonate accumulation may be plainly seen. The material effervesces vigorously when treated with dilute acid and has a pH of 8.32. Acidity commonly decreases with increasing depth in the soil body.

In general, the supplies of calcium are high. Potassium, phosphorus, and nitrogen appear to be adequate for normal forest pro-



duction. As might be expected, most of the nitrogen and available phosphorus is associated with the organic matter. The available phosphorus content is relatively high in the organic layers, low in the mineral soil layers exploited by roots, and high in the subsoil below the main root level. This distribution probably results from absorption of the element by plant roots in the upper mineral soil layers and its return to the humus layer in the annual leaf fall. Root development in most soils is shallow.

Water relations are especially important in the forest soils of interior Alaska. If the topographic situation is such that the soils are supplied with an abundance of water, subject to only very slow lateral movement, unfavorable ecological conditions result. Frozen ground is likely to be encountered at shallow depths, a waterlogged condition exists, temperatures are low, and aeration is poor. Tree growth is slow, if trees occur at all. On the other hand, soils that are supplied with small amounts of water are likely to be excessively droughty. It must be remembered that precipitation is scanty in the interior.

The most favorable conditions for tree growth are often found adjacent to waterways where the depth to frozen ground is several feet during the growing season, and where the ground water is moving, aeration is favorable, and soil temperature is adequate for normal growth. Pohle (*119*) noted the occurrence of forests along streams in northern Russia and suggested that the width of the timbered strip was dependent on drainage. Drainage is better in relatively coarse-textured soil materials (and the width of the timbered strip is greater) than in fine-textured soil materials. Evidently the width of the timbered strip along waterways becomes narrower with increasingly high latitudes.

Frozen ground is a common feature in soils of the Alaska interior. It is not present everywhere, however, and where it occurs its depth below the soil surface varies considerably influenced by drainage, topographic exposure, and vegetation type. Benninghoff (*14*) stated that seasonal thaw under spruce forests usually ranges from 2 to 6 feet. Thawing extends to greater depths under paper birch, quaking aspen, and grass. In general, it may be said that the existence of permafrost is a most fortunate circumstance. Thawing permafrost provides the vegetation with water that otherwise is not available because of the scanty rainfall. Without this water source large areas in the Alaska interior would, in all probability, become desertlike.

## Humus Layers

The effect of fires on the thickness of the layers of unincorporated organic matter varies with the intensity and frequency of burning. Light fires consume only the uppermost litter but severe fires may expose the mineral soil surface over all, or nearly all, of the burned area. Repeated light fires may be just as effective in destroying the forest floor as single severe fires. Complete destruction of the unincorporated organic matter was most frequently observed on well-drained rocky slopes or ridges where fuel and atmospheric conditions favor intense burning. It was also observed around the bases of spruce trees where the forest floor was dry because of interception of precipitation by the crowns (fig. 21). As explained earlier, accumula-

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FIGURE 21.—Deep burning around the bases of white spruce consumed all unincorporated organic matter. The mineral soil is covered with a layer of nearly pure ash.

tion of cone scales and other highly flammable debris around the bases of spruce trees is a factor favoring hot fires. Destruction of the forest floor to mineral soil varied from 0 to 100 percent in different fires and on different areas within a given burned tract. Examination of recent burns indicated that deep burning to mineral soil involved about 30 to 40 percent of the surface, even in fires so severe as to kill all trees.

## Physical Properties

### *Temperature*

No measurements of temperatures attained during forest fires are available for Alaska but indications are that they are high. Living spruce roots up to about 10 inches in diameter have been burned off and high temperatures have reddened both surface soil and rocks. Following fires, mineral soil temperatures are generally increased because of the reduction or elimination of the unincorporated organic matter. In undisturbed condition, this material is effective insulation. Another reason for higher temperatures on burned areas is the frequently darker color of the soil caused by charcoal. The higher soil temperatures that occur following burning are almost invariably reflected in a downward retreat of the permafrost layer. Frozen ground often occurs at depths of 12 to 18 inches under spruce forest in midsummer whereas in adjacent burned areas the depth may be greater than that reached by a 3-foot soil auger. The increases in soil temperature following fires are regarded as ecologically favorable although lethal levels may be reached at the soil surface occasionally and tree seedlings may be killed.

### *Moisture Relations*

Complete destruction of the forest floor on steep slopes, particularly those with southerly exposures, increases surface runoff and consequently decreases the amount of soil water available to plants. Increased evaporation losses also reduce the amount of available water. Reestablishment of forest growth on such sites is slow.

On land with gentle topography and on flat areas soil moisture relations do not appear to be altered appreciably by fires. The field capacity of the mineral soil layers, as judged by moisture equivalent values, is not much changed. In burned areas the supply of moisture available to plants is more stable, and hence more favorable, in spots where mineral soil has been exposed than where a mantle of charred organic matter remains. Organic matter on the mineral soil surface can hold large quantities of water, but this water is readily lost through evaporation. This results in wide fluctuations in moisture content that are very unfavorable to seedlings. Another consideration of ecological importance is the fact that a large proportion of the water held in organic matter is so tightly bound that plants cannot remove it; thus the wilting percentage is much higher in organic material than in most mineral soils.

In many areas of interior Alaska the frozen ground contains bodies of ice in the form of lenses, veins, and blocks. These ice masses are often large and occur under extensive tracts. When the natural vegetation is removed, as in clearing land for farming, the ice melts and the settling and caving produce an unstable, pitted surface. Muller (*100*) and others employed the term thermokarst for irregular land surfaces thus produced by the melting of ground ice. He reported that "Thermokarst land forms are commonly produced by forest fires, grass fires, deforestation, and stripping of the surface by man. Removal of the vegetative cover results in a more intense solar heating of the ground, melting the ground-ice and causing settling and caving of the ground."

Wallace (*163*) investigated cave-in lakes in the Nabesna, Chisana, and Tanana River valleys and remarked that "The effect of removal of the vegetal cover has been demonstrated in many places where caving has taken place in ground that had been cleared for construction purposes. In nature the initiation of a lake could result from such an event as the overturning of a tree by wind, with resulting uprooting of the vegetal mat." Forest fires must be a far more common cause of the melting of ground ice than windthrow of trees.

### *Texture and Structure*

If any changes in soil texture occur as a result of fires, the changes are slight. To alter texture there would necessarily have to be either fusion or baking of particles into larger stable units or a breakdown of particles into smaller units. Only rarely does either happen. Mechanical analyses indicate that the surface soil material, often deposited by the wind, has undergone little change in particle size since its deposition. Structural changes in the mineral soil as a result of forest fires also appear to be slight or lacking. Aggregate develop-

ment in most undisturbed mineral soils is slight because of the low content of organic and inorganic colloids. The aggregates tend to be both small and weak.

### *Runoff and Erosion*

Although quantitative information is lacking, it appears certain that runoff is increased on steep slopes that have been severely burned. This results from a combination of decreased infiltration rates and loss of the forest floor that reduces the rate of overland flow. This matter is examined in more detail in the section, Effect of Fire on Hydrologic Relations.

Erosion on burned-over forest land is surprisingly small in spite of the fact that the soil properties would lead one to conclude that they were easily eroded. Lack of extensive and severe erosion may be due to the low precipitation, the low intensity of rainfall in individual storms, the long period each year that the soils are frozen and snow covered, and the rapidity of revegetation of burned lands. Within a year or two following fires, mosses, liverworts, lichens, and higher plants usually develop, binding the mineral soil and protecting it from wind and water erosion.

Stream bank slumping following forest fires has been observed in the North by Preble (*122*), McKenna (*86*), and others. However, fires are not a major cause of bank slumping along northern rivers; bank cutting and slumping are common features on streams flowing through country long unburned (fig. 22).

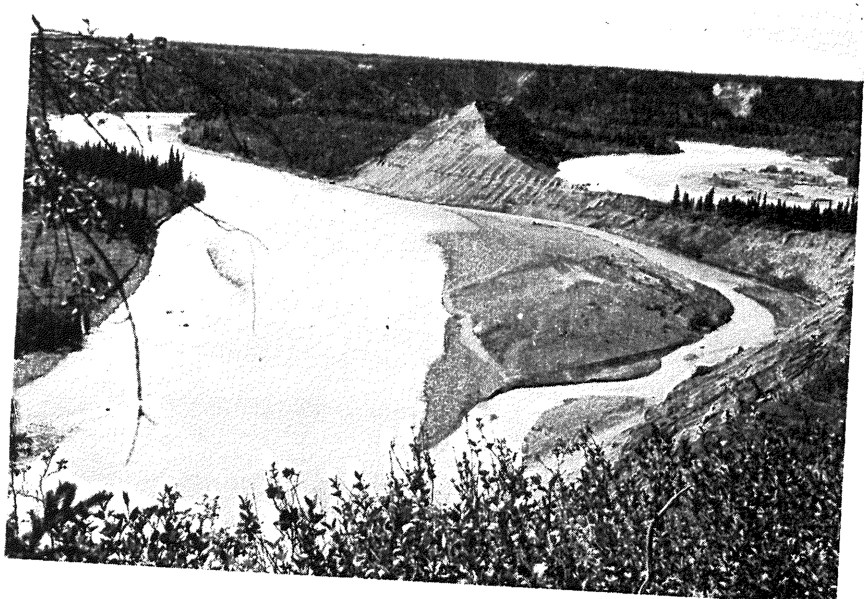

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FIGURE 22.—Bank cutting along the Tazlina River. Erosion of this type is very common and is not related to forest fires. It contributes to the silt load of the rivers. View upstream from a high bluff on the north side of the river, about ½ mile above the Richardson Highway crossing. June 1951.

Locally, steep slopes may be subject to landslides and slumping after the removal of forest vegetation. Muller (*100*) pointed out that a common cause of such mass movement ". . . is the concentration of ground moisture at shallow depth, immediately above the impervious permafrost or over the frost table prior to the complete thawing of the active layer." Safeguarding measures that Muller recommends include avoiding deforestation and the planting of trees and grasses.

At least two areas of drifting sands are known to occur in Alaska, one in the Kobuk River Valley and one north of Tok in the Tanana Valley. Neither of these areas was examined. Consequently it is not possible to judge whether destruction of natural vegetation by fire may have been a factor in initiating the erosion cycle.

## Chemical Properties

Soil acidity in the surface layers is invariably reduced by burning. Where the humus layers have been consumed and mineral soil exposed pH values of 6.5 to 7.5 are common. This results from ashing of the organic matter, which is relatively rich in the alkaline earths, calcium, and magnesium. Samples of pure ash from a burned white spruce forest had pH values of approximately 8.4. Reduction in soil acidity is a usual accompaniment of burning, as shown by the work of Eneroth (*44*), Isaac and Hopkins (*66*), Kivekäs (*72*), and many others.

Exchangeable calcium in the upper layers of the mineral soil is greatly increased by burning, the increase often being severalfold. This tendency is almost universal, having been reported by investigators in nearly all parts of the world. Exchangeable potassium and readily available phosphorus in the upper mineral soil layers are also increased by burning and this, too, has been reported by many investigators.

Nitrogen contained in organic matter that is consumed by fire is, of course, volatilized and lost to the site. Consequently it is certain that immediately after a fire the total nitrogen capital shows a reduction. However, all, or nearly all, evidence from northern forest regions points to an increased availability of nitrogen to vegetation following fires (*59*, *60*). Burning usually induces nitrification in mor humus layers. Even total nitrogen may increase to levels higher than before the fire. This may result from development of wild legumes with nodules containing symbiotic nitrogen-fixing organisms or it may result from increased activity of the free-living, non-symbiotic Azotobacter and Clostridium bacteria. The favorable nitrogen relations in most burned areas are confirmed by the dark green color of the plants, their vigorous growth, and the abundance of nitrate plants, such as fireweed and red raspberry.

Fires quickly make available the nutrient materials bound in organic matter. Thus immediately after burning a large part of the nutrient capital of the site is concentrated in the ashes on and in the upper mineral soil layer. A similar effect would result from adding fertilizer material. Microorganisms become active and seedlings which become established grow rapidly. Spruce seedlings established in burns may actually grow faster than seedlings of the same age in nursery beds.

## Soil Productivity

On most sites in Alaska, fire does not exercise a damaging effect on the soil. If it did, a large proportion of the forest soils in the Alaska interior would already be seriously damaged.

Certain categories of site are, however, unfavorably influenced and the effects may be of a lasting nature. Rocky, ledgy sites, especially on steep slopes, may be seriously harmed. Here the forest that existed prior to the fire was rooted not in mineral soil but in humus that had been built up over a long period of time. Destruction of the humus means destruction of the soil itself. Following fires, steep slopes with southerly or westerly exposures become critical sites for tree growth. Surface runoff is increased, the permafrost table is considerably lowered, surface soil and air temperatures are raised, and water losses through evaporation are increased. Such sites, for a long time, can support only the hardiest of plants. They may remain treeless indefinitely or bear open stands of slow-growing aspen. Re-entry of spruce is an extremely slow process even though spruce may have been the type present before the fire occurred.

No possible justification of uncontrolled wildfires can be found in the realm of soil science. Such fires can never be justified or even excused on the basis of beneficial effects on the soil, despite the fact that fires may have favorable effects on certain properties. Contrariwise, the writer regards uncritical allegations of destruction of the soil and deterioration of the soil as less than strong arguments against uncontrolled fires. Occasionally destruction of soil by forest fires does literally occur but on the majority of burns destruction or deterioration of the soil would be impossible to prove.

## EFFECT OF FIRE ON HYDROLOGIC RELATIONS

The relation of forests and other vegetation to hydrology in the interior of Alaska is poorly understood. Although quantitative data bearing on the subject are very scanty, vegetation probably exercises a considerable influence on the water regime.

Runoff in rivers draining areas of permanently frozen ground represents a high proportion of the total precipitation. Alter (*7*) stated that discharge measurements made by the Geological Survey on the Yukon River indicate that the runoff exceeds 60 percent of the precipitation. Shimkin (*143*), in his report on the Fort Yukon area, remarked that "An outstanding characteristic of Arctic rivers draining areas of permanently frozen ground is that the runoff from their basins approximates 55 to 65 percent of the precipitation as opposed to 15 to 18 percent for rivers in temperate areas, such as the Mississippi." Shimkin noted that "This means that the flooding, eroding and silt-carrying capacities of these rivers . . . are nearly four times as great as might be indicated by normal experience."

Removal of the vegetation mantle as a result of fire may be expected to increase the already high ratio of runoff to precipitation. Increased amplitude between high and low water stages may also be expected. The qualitative effects of vegetation removal may be anticipated even though quantitative information is not available. Ellsworth and Davenport (*43*), in discussing the surface water supply in the Yukon-Tanana region, wrote as follows:

> The moss that forms a heavy coating over most of the country probably regulates the distribution of the run-off during the summer as much as any factor. It is quite generally the opinion among the older residents of the country that the flow of the creeks does not hold up as well after a rain now as when work first commenced. That probably is due in part to the fact that the moss covering on the older creeks has been largely removed by fires and other agents.

The same authors in their discussion of the Crooked Creek drainage basin in the Circle district observed that:

> The run-off from the area is less than from adjoining areas. The creeks are liable to a very low minimum discharge and, owing to the steep barren slopes, are flashy in character. Nearly all the timber in the headwaters has been cut off and much of the basin has been burned over.

Marshall (*90*) in describing placer mining in the Koyukuk region, stated that the water problem was exceptionally serious because most of the creeks are small and their volume of water has been decreased by removal of the forest vegetation. Marshall (*90, pp. 173–174*) quoted at some length the views of an oldtimer on the upper Koyukuk to the effect that carelessness with fire had resulted in widespread burning of the forest and that, with its destruction, water supplies for mining became scarcer.

Tundra and bog vegetation, as well as forested areas, must exercise a regulatory influence on runoff. Auer (*8*), in his investigations of peat bogs in southeastern Canada, noted that "The burning off of the moss covering may have the effect that the surface of the peat bog is no longer capable of detaining water of sudden rain, but the water breaks through the peat bog in many places and flows away as rapid rivulets."

The problem of water supplies in the Alaska interior will probably become more acute as population increases and the Territory is developed. With increased demands for water, it seems certain that increased attention will be given to the hydrologic role played by vegetation.

## EFFECT OF FIRE ON ANIMAL POPULATIONS

One of the important resources of the Alaska interior is the wildlife, especially the fur bearers and the big game. From it both the white population and the natives derive very substantial economic benefits. As early as 1908 Osgood (*106*) recognized this fact and expressed himself as follows:

> In addition to its inherent values game is of great pecuniary importance to the country it inhabits on account of the money spent there by visiting sportsmen. Not only are substantial revenues derived through the direct sale of hunting licenses, but considerable sums are distributed in the payment of travelling expenses and in the employment of guides, packers, boatmen, and others. To Alaska and Alaskans such considerations are not without importance, for the development of this northern Territory will in the long run require the utilization of every

resource. If lands unsuitable for mining or agriculture can, by reason of the wild game inhabiting them, be made a part of the permanent resources of the country, they have a substantial value. If properly husbanded the game becomes a perpetual source of pleasure and profit, whereas if ruthlessly sacrificed to immediate desires the region now made attractive by it will lapse into a comparatively uninteresting and useless waste.

More recently, the Canadian Bureau of Northwest Territories and Yukon Affairs (*25*) published the following statement:

> As the fur trade has been and will continue to be the main support of the Indian population, and as forest-dwelling animals supply the Indian with meat, it is felt that one of the greatest values of the forests of the Northwest Territories lies in the habitat which they provide for game and fur bearing animals.

The effects of fires on the wildlife resource are of vital importance to the future of Alaska and its citizens.

The subject of forest fires in relation to wildlife has many controversial aspects. Much of the controversy appears to stem from failure to distinguish between accidental wildfires, whose occurrence with respect to time, place, and intensity is largely fortuitous, and prescribed fires which may be used as a management tool. Although generalizations are admittedly hazardous, informed opinion seems to be that accidental fires, whose time of occurrence and geographic location is determined by a chance lightning strike, a cigarette discarded before it was out, or by the campfire of a careless individual, cannot be regarded with favor.

In 1933 Aldo Leopold (*81*), the leading exponent of game management in the United States at that time, wrote, "Any fire, however light, of course makes a clean sweep of all ground nests and helpless young. This loss of nests and young is undoubtedly the heaviest item in the direct mortality from fire. The peak of the fire season in most regions is the peak of the nesting and fawning season." In 1923 Leopold (*80*) stated that ". . . fire does no good to game which forestry would not likewise do, and fire does enormous damage to game which forestry would avoid." The significance of this observation is not widely enough appreciated. In 1934, Dymond (*41*), in discussing the conservation of game and fur-bearing mammals, expressed the view that "The necessity of preventing forest fires is now universally recognized, but it may be worthwhile adding that fire not only destroys the forest as such, but eliminates the wild life and renders the burned area unsuitable for a long period as a home for many species of game and fur-bearing animals." Gabrielson (*46*) stated,

> Rapid running forest fires, particularly crown fires, may be very destructive to wildlife. If they occur in the nesting season of birds, the broods of the year and often the breeding stock are destroyed. Many parent birds, particularly those sitting on eggs that are nearly ready to hatch, will stay on the nests until suffocated or burned. . . . Generally speaking, however, on the basis of present knowledge, fire is so great an enemy of both wildlife and forests that there is an increasing amount of fire patrol, both on public and on private forest lands. This should in the long run be exceedingly beneficial to wildlife.

Fur-bearing animals in general appear to be adversely affected by most severe fires. This applies particularly to animals that are unable to take refuge in water and in situations where the fires are repeated. Small mammals, many of which serve as food for fur bearers, are killed when fires destroy their habitats (*45*). The marten (*Martes americana*) one of the most valuable fur-bearing animals in northern forests, probably is more menaced by forest fires than any other fur bearer. Seton (*141, pp. 491–493, 497*) regarded fires as especially damaging to marten and expressed himself as follows: "A forest fire of 100 square miles means the destruction of all martens within that 100 square miles. They cannot escape. The smoke pursues the fugitives, and overcomes them. Their food is destroyed in the stricken area." In 1922 representatives of one of the great fur-trading companies in Canada, presumably the Hudson's Bay Company (*1*) stated,

> It is a common complaint of the Indian that fires have crossed his 'marten,' or hunting grounds, with the consequent destruction of all such game as marten, fisher [*Martes pennanti*], fox [*Vulpes fulva*], ermine [*Mustela erminea*], and lynx [*Lynx canadensis*]. This necessitates a 'change of venue' for his activities, or the confining of his attention to the trapping of beaver [*Castor canadensis*], otter [*Lutra canadensis*], etc., thereby reducing the numbers of these animals more rapidly.

During the summer of 1950 the extensive fires northeast of Fort Yukon were frequently lamented by Alaskans because they destroyed the forests in what was reportedly some of the finest marten country in the Territory.

Of particular interest in this connection is a report by Angus Brabant (*18*), Fur Trade Commissioner of the Hudson's Bay Company, published in 1922. Brabant expressed the view that recurrent forest fires were a threat to the fur trade. He observed,

> Our returns from certain districts that have experienced the devastation of forest fires, over what is but a comparatively small part of the total area, have indicated a marked decline in fur production for many years after the occurrence of fires. These conflagrations have not only destroyed magnificent stretches of Canadian forest, sweeping away valuable timber that will require a generation to reproduce, but they have wiped out the food supply and the shelter of the fur bearers.

Brabant also stated, "The Company's experience is that the finest furs are obtained in the most densely wooded districts." This interesting observation is confirmed by others (*1*). Brabant (*18*) pointed out that "The appalling losses to the fur trade which are traceable to forest fires affect a very considerable portion of our population, the many thousands who earn a living as trappers, traders, fur dressers and dyers, garment makers, merchants and salespeople."

Exceptions doubtless occur but it seems reasonable to assert that the general effect of uncontrolled fires on fur bearers is unfavorable.

## Moose

The opinion is frequently expressed that forest fires create more favorable conditions for moose (*Alces americana*) by destroying climax stands of white spruce or stands of black spruce and permitting the establishment of subclimax communities of willows, aspen, and birch, together with other browse species. That changes in vegetation almost invariable follow fires is readily observed. It is not nearly so certain, however, that the species composition of the vegetation which follows wildfires will be that most desired.

In 1953, Leopold and Darling (*82*), writing of Alaskan conditions, observed, "The mere passage of a fire through timberland does not necessarily create optimum conditions for moose. Some burns produce a grassland stage; others come back in pure spruce; many produce aspen with little birch or willow which are the most palatable and productive browse plants." Already it appears that the great burn of 1947 on the Kenai Peninsula, involving a net area of perhaps one-quarter million acres, will have a short-lived value as a wintering ground for moose because of the entry of spruce reproduction in quantity, the failure of willows to appear in numbers sufficient to withstand heavy use, and the fact that most of the browse is aspen sucker growth, which does not successfully withstand heavy browsing. This situation is not unique. Although most often aspen and birch come in after fire as pointed out earlier it is not uncommon for burned areas to reproduce to essentially pure spruce forest. It should also be recognized that establishment of browse species following severe fires is not immediate; years may pass before burned areas again support an appreciable amount of food for moose (*109*). It is doubtful that moose can reproduce rapidly enough to utilize fully the browse in extensive burns before it grows out of their reach. This would be a problem in tree species such as aspen, birch, and the larger willows such as Scouler and Bebb.

The studies by Cowan, Hoar, and Hatter (*35*) in British Columbia led them to the conclusion that it is desirable for moose to have access to " . . . older stands bearing well grown coniferous trees . . . " in order that they may obtain certain nutrients. These investigators reported that their study pointed "to the desirability of winter range for browsing ungulates upon which there is a variety of palatable species predominantly in an early stage of growth, but with an intermixture of stands of other ages including areas bearing sub-climax or climax associations, including palatable coniferous species. The most desirable winter range for moose will be one well diversified as to species composition and age of stands, but predominantly of new growth following deforestation."

The preponderance of evidence favors the conclusion that moose are today common or abundant in some regions throughout the North where formerly they were rare or not known to exist. This has been repeatedly asserted with regard to the Kenai Peninsula, a region now famous for both the numbers and size of its moose. In 1901 Osgood (*105*) stated, "According to report the moose has but recently appeared in the Cook Inlet region; the older Indians say no moose were there when they were boys." Similar statements were made by Roosevelt and others (*131*), Niedieck (*102*), Osgood (*104*), Dufresne (*39*), and Camp (*24*). Dufresne (*39*) described the situation as follows:

> In the year 1883 a forest fire raged for months on Kenai Peninsula. Shortly thereafter the caribou herds vanished. Coincident with this rapid passing of the caribou appeared the moose which were practically unknown on the Kenai before the big fire. Today, not a single caribou exists on the Peninsula, but the place is famous for its moose herds. The explanation is not complex. Fire destroyed the lichens on which the caribou feed; fire produced in its wake abundant growths of willow, birches, and cottonwoods relished by the moose.

That moose were practically unknown on the Kenai Peninsula before the fire of 1883, mentioned by Dufresne, may be doubted. In the Tenth Census of the United States, 1880, Petroff (*116*) described certain delicacies served at a native feast in Chkituk (on the north side of the Kenai River, above the village of Kenai) and specifically mentioned dried moose nose. In addition, he stated, "The variety of native animals is very great. . . . The deer here is apparently a larger cousin of the reindeer, the woodland caribou. Moose, single and in family groups, can be found feeding through the low brushwood and alder swamps." Abercrombie (*4*), in his report of 1884, quoted Ivan Petroff, who was then in the Customs Service at Kodiak, as follows: "Forage can be gathered in the vicinity of Fort Kenai during the summer to keep the stock during the winter. The climate is not more rigid than that of Montana. Moose abound, furnishing an article of food preferable to beef." Petroff was familiar with the Cook Inlet region and must have written the above statement not more than a year or two after the fire of 1883.

Karr's 1887 report (*67, p. 237*) included a map with the Kenai Peninsula labeled as supporting bear and moose. The Eleventh Census of the United States, 1890 (*159, p. 70*), only 7 years after the fire of 1883, contains a statement on the Kenai Peninsula, as follows: "The forests and valleys of this region are still filled with numerous droves of moose . . . and furnish a rich hunting ground for the Tnainas of Nikishka and Kenai." That moose were actually present on the Kenai Peninsula at a very early date is demonstrated by the findings of Laguna (*75*) in her excavations on Yukon Island in Kachemak Bay on the south end of the peninsula. Moose bones were found in four layers (Period I, II, sub-III, and IV) representing four periods of habitation.

Fires, through their effect on vegetation, probably favor an increase in the population of moose, but there is no proof that burning was uncommon on the peninsula prior to 1883. Apparently the earliest written record of a forest fire in Alaska is that of the Russian mining engineer Doroschin (*37*), who ascended the Kenai River in 1850. He encountered a forest fire which prevented him from completing his investigations of the gold resources of the region.

The available history of moose on the Kenai Peninsula was investigated because the presence or absence of fires does not satisfactorily explain the appearance and disappearance, or the existence of large or sparse populations of these animals. In this connection it may be pointed out that in the discussion of the paper by Chatelain (*32*)

Urban C. Nelson remarked, "I think probably the conclusion that the moose abundance there [on the Kenai Peninsula] is purely the result of burns might be open to question."

Movements of moose into areas where they were previously rare or not known to exist has extended to sections not influenced by fire. Leopold and Darling (*82, p. 87*) stated,

> On the northern and western fringes of the Alaskan moose range, willow is not a secondary plant invader but rather it is part of the riparian climax vegetation, the uplands being tundra. The factor which governs the abundance of willow here is not fire, as in the central and southern spruce forests, but probably temperature. We postulate that the recent spread of moose into predominantly tundra areas must be correlated with the gradual Holarctic warming that is known to have occurred in the past half century.

Turner (*157*) recorded the killing of a moose in the vicinity of Pastolik, near Saint Michaels, in the early winter of 1876. This was said to be the first instance of moose occurrence, on the seacoast, north of the Yukon River. In 1887 Nelson (*101*) remarked that "[moose] lead a roaming life, and where they may be numerous one season none may be found the next. The fur traders and Indians claim that the moose has been found west of Fort Yukon only within the last twenty-five or thirty years, and that only within the last ten years have they been killed below Anvik and Mission, on the Lower Yukon." Evidently the movement westward and northward, into unburned country, is continuing at the present time. The movements of the moose, as they extend their range, are most perplexing.

In the treatise on the deer family by Roosevelt and others (*131*), Andrew J. Stone prepared the section on moose. He offered an interesting explanation for the increase in the moose population in various areas, including the Kenai Peninsula, as follows:

> They are now numerous in a very large territory in northwest British Columbia, through the Cassiar Mountains, on Level Mountain, and throughout the head waters of the Stickine River, where thirty years ago they were unknown. They are now abundant on the Kenai Peninsula, Alaska, and in other sections of the North where at one time they did not exist. Acquisition of territory by so wary an animal as the moose can only be accounted for in one way. Many years ago the Indian tribes occupying these sections were very numerous and inimical to moose life, but, since the Indians have dwindled from thousands to insignificant numbers, the moose finds comparatively unmolested life. This I know to be the case on the Kenai and in the country referred to in northwest British Columbia; and there are many similar changes in conditions in other parts of the North, notably in the Nahanna River country, north of the Liard, where the entire tribe of Indians that once hunted the country have died out, to the very great increase of moose.

Fires have, in numerous instances, resulted in the establishment of rapidly growing, healthy forest stands of desired tree species. Silviculturists in some regions have already learned how to use fire as a tool to achieve their objectives. The gradual recognition among foresters of the useful role that prescribed burning may play in forest management has been accompanied by increased attention to protection against accidental wildfires. The relationship between fire and game management is in many respects analogous to that of fire and forest management. In both fields fire may be used as a tool to favor establishment of new vegetation, to influence or control species composition, and for various other purposes. But neither in forest management nor in wildlife management can uncontrolled fires be justified.

The solution of the problem is one that requires a strictly objective approach. After the forester or the wildlife manager has ascertained that fire is the most economical and effective means of attaining the objectives of management, he should use it, and be prepared to accept the same professional responsibility for results as a silviculturist marking timber in a cultural operation or in a harvest cutting to obtain natural reproduction. Leopold and Darling (*82, p. 89*) stated,

> The wildfires of the past inadvertently improved many Alaskan ranges for moose at an exorbitant cost in timber, watershed cover, and caribou range. It is unthinkable that we can permit unregulated burning to continue. The ambitious, but sadly underfinanced fire control program of the Bureau of Land Management (Division of Forestry) is the first positive step to curb this destruction. Assuming that wildfire can be arrested in the future, there remains the opportunity for the *controlled* use of fire to improve selected winter ranges for moose where other values may be considered subservient.

## Caribou

The problem of fires and caribou is in a category wholly different from that of fires and moose. Unlike the moose, which prefers pioneer plant communities or at least vegetation representing early stages of successional development, the barren ground caribou normally lives in environments characterized by climax plant communities, tundra, and forest-tundra transition.

Movements of caribou exhibit some of the same vagaries noted in the movements of moose. In early times, for example, caribou were known on the Kenai Peninsula (*116, 79, 6*), but are not now present. Perhaps the last caribou observed in the region is that mentioned in 1912 by Shiras (*144*) who wrote "a good-sized stag was seen south of Benjamin Creek by a party of surveyors last July [1911?]." Dufresne (*39*) associated the disappearance of caribou from the Kenai country with a forest fire that burned in the region in 1883. Other reasons for their vanishing have been suggested by earlier writers.

Daniel G. Elliott (*131, p. 279*) observed "On the Kenai Peninsula and surrounding districts head hunters, both white and red, have nearly exterminated the species, and the increased means of transportation to and through their country, the large number of hunters, greatly added to annually, and the improved firearms, would seem to foretell the extinction in a brief period of this fine animal in the regions where he is accessible."

Allen (*6*), writing of the specimen of caribou that Andrew J. Stone collected on September 24, 1900, quoted Stone as follows: "Caribou . . . are already very scarce on the Kenai Peninsula, and will doubtless soon be exterminated, the region being greatly frequented by visiting sportsmen, while native hunters kill the moose and caribou for their heads, disposing of them at good prices for shipment to San Francisco." And Phillips (*118*) remarked that the caribou on the Kenai Peninsula "vanished as rapidly as the buffalo when modern rifles were sold to the natives by enterprising American traders." As late as 1898 large bags of caribou were at least occasionally taken. Thomas C. Dunn, President of the Munina Alaska Gold Mining Co., in an account of a hunting expedition in 1898 of Harry C. Lee (*79*), stated that Lee found game abundant between the head of Chugachik Bay (at the upper end of Kachemak Bay) and Tustumena Lake. Lee killed three caribou.

It seems reasonably certain that the increased tempo of burning by forest fires in Alaska since 1890 unfavorably affected caribou populations. Extensive forest fires, particularly in the lichen-rich forest-tundra transition or woodland areas, have without doubt destroyed large portions of the caribou range. Unlike moose browse, which in favorable circumstances may develop in a few years following fires, caribou range requires very many years for recovery after it has been damaged by fire or by overgrazing.

Fruticose lichens of the *Cladonia* group, *Cetraria* spp., and *Stereocaulon* spp., together with certain beard lichens such as species of *Usnea* and *Alectoria* growing on trees, form the principal winter food of caribou and reindeer (*40*, *2*, *84*, *142*, *113*, *65*). These lichens are all readily killed by forest fires and their recovery is extremely slow as already noted in the section Herbaceous Plants. Aaltonen (*2*) reported that even 20 to 30 years following fires the reindeer lichens in Finland (chiefly *Cladonia alpestris*, *C. rangiferina*, *C. sylvatica*, and *C. uncialis*) occurred only sparsely and attained heights of only a few centimeters.

Lynge (*84*) noted that *Cladonia alpestris* and *C. sylvatica* grow very slowly in Norway; he estimated that they would require a minimum of 25 to 30 years for full development, even under favorable conditions. Lynge observed burned areas where, after 50 years or more, *Cladonia alpestris* was scarcer and less well developed than in adjacent unburned areas. In 1926 Palmer (*108*) stated,

> It may take a burned-over lichen area as much as 25 years to come back; or where so badly burned that the cover of humus is destroyed, the changed site conditions may result in a recovered stand of inferior species, or virtually in a permanent removal of the lichens, so far as practical grazing use is concerned. In view of the importance of the lichen areas for winter grazing, it is vital to all reindeer men to guard against fires; and because of the damage to game and fur animals and to tree growth, it is the concern of everyone that fires be prevented and fire protection sought.

In 1945 Palmer and Rouse (*110*) expressed the view that "A depleted lichen range under complete protection requires from 20 to 40 years for restoration to the original density and height growth." These authors studied the recovery of tundra range after various treatments intended to simulate grazing by reindeer. In an unpublished report on burned woodland or timbered range, Palmer[6] stated, "A full recovery in lichen composition comprising chiefly short growth forms takes place in about 50 years, following destruction by fire. For full return to the original cover of tall growth lichens it is indicated that considerably more than 100 years will be required." Manning (*89*) believed that complete recovery would require 30 years in the country on the east side of Hudson Bay. Hustich (*65*) quoted the following estimates of the length of time required for recovery of reindeer lichens following fires: Itkonen, 40 to 50 years; Sarvas, 30 to 40 years. Hustich estimated at least 40 years for recovery in northeastern Canada.

Variations in estimates of the length of time required for redevelopment of the lichen vegetation after fires are influenced by differences of opinion of what constitutes recovery, by differences in the intensity and extent of fires, and by differences in site and microclimate. A conservative estimate of the usual length of time would appear to be 40 to 50 years, but in some instances it may be much more. A half century, more or less, is a very long time for caribou range to be out of production. Burned areas are avoided by caribou and, as Schierbeck (*136*) has pointed out in Nova Scotia, the return of lichens to such regions does not necessarily mean the return of caribou. Even though the caribou are great travelers it seems reasonable to suppose that they are adversely affected when their range is broken up into small, often isolated, fragments by recurring fires. It also appears probable that under these conditions excessive local overgrazing is more common than on more extensive, continuous range.

The effects of severe fires on fur bearers may be summarized as generally unfavorable. The effects of most fires on moose are generally favorable, but caribou are adversely affected by all fires. Judgment of whether forest fires are good or bad must usually be based on a consideration of the sum total of values involved. These values are timber, wildlife, soil, water, and aesthetic or recreational values. In management, priority may be given to one or a combination of these values, but only after due consideration of the others. The principle of multiple use should be applied to the extent that it is consistent with efficient resource management. Uncontrolled wildfires have no place in either forest or wildlife management. The ultimate place of prescribed burning in Alaska cannot now be stated. Neither the forester nor the wildlife specialist in Alaska today has the requisite knowledge to enable him to use prescribed burning on anything more than a purely experimental basis. There is a great opportunity and need for research on this problem.

## EFFECT OF FIRE ON ECONOMIC DEVELOPMENT

The available natural resources will, in the long run, determine the economic development of the Alaska interior. Without reasonably complete information on these resources, prophecy on future development becomes particularly hazardous.

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[6] PALMER, L. J. CARIBOU VERSUS FIRE IN INTERIOR ALASKA. (A STUDY OF BURNED-OVER LICHEN RANGES.) U. S. Fish and Wildlife Service. 33 pp. 1941. [Typewritten report.]

The nature and extent of Alaskan resources has long been a subject of warm dispute. Ivan Petroff (*115*), writing in 1880, prefaced his statement on the agricultural and pastoral resources of Alaska as follows: "So much has been said upon this topic, of frantic declamation on one hand, and indignant remonstrances on the other, that we shall be very cautious in our presentation of what we believe or know to be a fact." There is a tendency toward extreme views when Alaskan resources are under consideration. At one pole are the extreme pessimists who would "give it back to the Indians"; at the other pole are the extreme optimists to whom the expression "land of milk and honey" is a fitting characterization of even the leanest of regions. More temperate and more realistic would seem to be the view that interior Alaska possesses important natural resources that will one day be a firm basis for economic developmentbut that these resources are relatively modest and need to be carefully conserved and used.

Among the resources that, wisely used, can support an economy in perpetuity, the forests, with their great potential production of cellulose, occupy an important place. They are of direct importance as a source of forest products and of indirect importance as a habitat for wildlife and as a feature of the tourist trade.

The threat of forest fires to the economic development of Alaska has been recognized for years. The earliest and strongest condemnation of fires did not come from professional conservationists but from members of the Geological Survey. In 1911 Brooks (*21*) deplored the widespread forest fires that he saw every summer as follows: "It appears to the writer that at the present rate of consumption and destruction by forest fires the timber of the Yukon-Tanana region will not be sufficient for the placer-mining industry, let alone any possible development when this stage has been passed."

In 1915, Ellsworth and Davenport (*43*) pointed out, "One of the determining factors in the mining industry is the timber supply, not only for fuel but for constructing flumes, mine supports, and buildings. So far demands have been fairly met by the local growth, but large inroads have been made by both legitimate use and by forest fires, and the distance timber has to be transported is gradually increasing with a corresponding increase in cost."

In 1915 Henry S. Graves, then Chief Forester of the Forest Service, visited the interior of Alaska. He was impressed with the appalling losses resulting from fires and in 1916 made the following statement (*54*):

> The value of the interior forests should not be gauged by the size and quality of the trees for lumber, or their place for possible use in the general lumber markets of the Pacific coast. They have rather an economic value as a local necessity that can be measured by contrasting the developments that will take place with their aid, with the conditions that would exist without them and will exist if they are destroyed. Nor can the economic position of the forests be judged by their aggregate extent and total volume of wood and timber. In a country of vast distances, sparse population, high cost of labor, and meagre facilities for transportation, it is the presence of forest supplies immediately at hand that may make the development of industry and the establishment of homes in a given locality possible.

Drake (*38*), investigating the birch forests in the Susitna Valley, noted the slight value which the people of the region placed on the timber resources. In 1923 he observed,

> The attitude that the local forests are of little value is detrimental to the region's development, and public-spirited citizens should endeavor to bring before the public mind the necessity of conserving the timber that will be needed for dwellings, farm buildings, bridges, telephone poles, mine props and that will attract wood-using industries. . . . while no extensive market for this timber has been found to date, one will eventually be secured and steps should be taken to protect the forests until the time for this exploitation is at hand.

What is needed is an awareness of the public that when uncontrolled fires sweep through forest stands damage is done to the community and Territory of which they are a part. What harms a country also harms its citizens.

Interior Alaska simply does not have "timber to burn." Following a severe fire, a minimum of 100 years and an average period of about 160 years must elapse before timber suitable for sawlogs again develops on the burn. It is doubtful if the development of the Territory can wait that long! Occasionally uncontrolled fires are condoned because they burn in young timber not of commercial size or because they burn in areas supporting growth that even the most optimistic forester would admit had no present or future commercial prospect. Two obvious facts may be pointed out in this connection. First, young trees are always small and all large trees were once young. Second, fires show no respect for values; seldom, if ever, does an extensive fire burn solely in scrub growth. Some potentially valuable timber is destroyed in every extensive burn.

The relation of uncontrolled fires to the wildlife resource has already been discussed. It seems apparent that the widespread burning that has occurred during the past half century or more has not resulted in a land teeming with fur bearers and big game. It may be doubted that more burning will produce such a result in the future.

Many thoughtful observers believe that the tourist trade, based on recreational resources of all kinds, may well become one of interior Alaska's most important sources of income. Here, again, unburned landscapes are an asset and extensive burns are a liability. Few persons intent on developing tourist or other recreational facilities would choose a recently burned area. An extensive fire in the vicinity of an established lodge would certainly not be a business asset.

The nuisance of forest fires extends far beyond the immediate limits of the area burned. Smoke, spreading over wide areas, is a source of annoyance to say the least; it may actually disrupt air travel and become a hazard to human life. MacDonald (*85*) gave an eloquent description of the restrictions which smoke from forest fires imposes on plane travel. For three days his plane was grounded at Edmonton. In Alaska where plane travel is commonplace, smoke has more than once prevented normal operations.

## SUMMARY AND CONCLUSIONS

Of the land area of 366,435,000 acres in Alaska, about 60 percent or approximately 219,861,000 acres, is in the interior. In this vast area, tree growth is the dominant vegetation on most of the land below an altitude of about 2,500 feet. Nearly 120 million acres bear sufficient tree growth to warrant designation as forest land.

The Alaska interior has a continental climate with great extremes of temperature. Summer temperatures as high as 100° F. are known and in the winter temperatures as low as −78° F. have been recorded. Long days prevail during the short summer. Precipitation is light north of the Alaska Range, amounting to about 10 to 15 inches annually; south of the Alaska Range it averages around 20 inches. The growing season is usually less than 90 days.

The forests of the interior present a mosaic of types resulting from the effects of forest fires and from variations in site. The latter are associated with differences in water relations, permafrost conditions, and soil aeration. Of the 120 million acres of forest land, some 40 million acres are believed to be commercial or potentially commercial. Some 80 million acres of the interior bear sparse forests of open woodland.

Sample plots indicate that at a rotation age of around 160 years white spruce stands may average about 15,500 board-feet or 3,900 cubic feet per acre. Indications are that at 160 years of age, 80 percent of the trees would be 5 inches in diameter and larger and that 20 percent would exceed 12 inches in diameter; some of the trees would then be 18 to 20 inches.

On the 40 million acres of commercial or potentially commercial interior forest land it is estimated that there are some 32 billion cubic feet or around 180 billion board-feet of timber. The forest resource is so tremendous and so important to the future economy of Alaska that it merits full consideration in the national program of forest conservation.

Alaska has been subject during prehistoric and historic time to extensive and repeated fires. Northern forests are highly flammable when dry. The branches of dominantly coniferous trees frequently persist nearly to the ground and often support beard lichens, which have a tinderlike quality. The ground is commonly covered with lichens, mosses, and small shrubs that readily carry fire. Man is the principal cause of fires but lightning is also an important agent. An average of at least a million acres of forest land has burned annually for the last half century.

As a result of fires, the climax white spruce stands on moderately well-drained sites have been replaced, over wide areas, by stands of paper birch and quaking aspen. Both of these species are shorter lived than white spruce, both have shorter pathological rotations, and their timber cannot be stored on the stump as it can in white spruce forests. Fires have had less effect in changing forest composition on the forested lowland areas where black spruce represents a physiographic climax. In the absence of repeated burns occurring at short intervals, black spruce tends to perpetuate itself.

Revegetation of recently burned areas by forest trees is usually prompt. Few, if any, areas can be found that are literally barren as a result of single fires even though the burning may be severe. Two conditions are necessary for restocking of burned areas by forest growth—supply of viable seed and exposed mineral soil. Both of these conditions are fulfilled on most of the burned areas and paper birch, quaking aspen, or spruce—either pure or in mixture—are developing. Only on critically dry sites, such as steep slopes with a southerly or westerly exposure, excessively drained alluvium, or rocky slopes without mineral soil, has natural reforestation failed in any important degree. In burned areas seedling reproduction tends to be restricted to exposed mineral soil; charred forest floor material represents a very poor seedbed, presumably because of the unstable moisture supply and high surface temperatures. The outstanding effects of fires are that vast amounts of existing timber are destroyed and that the subclimax types (principally quaking aspen and paper birch) are greatly increased at the expense of the white spruce type.

Paper birch is an early stage in forest succession, comparable to the quaking aspen type. Paper birch produces large numbers of light, easily disseminated seeds and forms even-aged stands. By the time paper birch stands are about 80 years old, white spruce frequently becomes prominent as an understory component. At 100 to 120 years of age the paper birch declines and the spruce increases. Barring major disturbances, such as fire, paper birch stands are gradually converted to white spruce-paper birch forests. Fires tend to perpetuate the birch and reduce the representation of spruce. Following fires, there is usually some sprouting of birch stumps, but the main reason for the decline in spruce is that seed of that species is lacking or in scanty supply.

The white spruce-paper birch type represents a stage of succession comparable to the white spruce-quaking aspen type. It is more advanced than either the paper birch or quaking aspen types. White spruce-paper birch stands may develop immediately after fires or they may result from gradual entry of white spruce into stands that were initially pure paper birch. Spruce in mixture with birch suffers considerably from crown friction. Even so, spruce gradually develops into a dominant position. Defect becomes high in birch at about 100 years of age and the basal area of spruce is likely to exceed that of birch in stands over 130 years of age. In the absence of disturbance, white spruce-paper birch stands gradually change into essentially pure, relatively open stands of white spruce. Fires tend to perpetuate the birch and reduce the proportion of spruce. Here, however, the birch is not favored as much nor is spruce repressed as greatly as in young stands.

The quaking aspen type is a stage of forest succession analogous to the paper birch type. Aspen regeneration after fires is often abundant, from both root suckers and seed. The stands tend to be even aged. In the absence of fire or other disturbance, aspen occupies the land for one generation only except on excessively dry southerly or westerly slopes where it may persist indefinitely. White spruce, which may have started with the aspen immediately after a fire, or which usually enters the stand later, gradually dominates the site. White spruce in aspen stands is subjected to less suppression and crown deformation than in paper birch forests. Aspen is a short-lived species; decay is

common in 60-year-old stands. Fires in aspen stands perpetuate aspen and destroy practically all the white spruce.

The white spruce-quaking aspen type is a stage of development analogous to the white spruce-paper birch type. White spruce-quaking aspen stands may become established immediately following fires, but more characteristically they arise as a result of succession, with the spruce gradually invading essentially pure aspen communities. In the absence of fire, spruce gradually replaces the aspen, and relatively open stands of spruce result. Elimination of the aspen is rapid in stands older than 60 years. Fire perpetuates aspen, largely because of the capacity of the species to produce root suckers.

Balsam poplar forms essentially pure stands on recently deposited alluvium. Many stands represent the first forest stage in a primary successional series. Following fires, the species also invades upland areas adjacent to large streams. Evidently balsam poplar may occupy flood-plain areas indefinitely if they are subjected to periodic overflow with deposition of silt and other alluvium. On relatively stable sites, white spruce gradually assumes dominance, replacing the poplar. Fires are not as common in the balsam poplar type as in other forest communities but they are known to occur. Following fires, balsam poplar reproduces by both root suckers and seeds. In many ways the species behaves like quaking aspen.

The white spruce type is the climax forest on well-drained lands in the interior. It is of widespread occurrence and is primarily responsible for the vegetational aspect of the landscape. Young stands are often essentially even aged but become uneven aged as they grow older. High density is characteristic of white spruce forests established immediately after fires. If the stands develop as a result of replacement of aspen, paper birch, or balsam poplar, they are likely to be relatively open. White spruce is probably longer lived than any other tree in the Alaska interior. Ages of over 300 years have been determined. Diameters of occasional trees on especially favorable sites may exceed 36 inches, and total heights may exceed 100 feet.

Single light surface fires in white spruce do not result in complete destruction of the stands. Such fires create small openings where seedlings of spruce, paper birch, and occasionally aspen and willows develop. Single severe fires generally result in complete destruction of existing stands and their replacement by subclimax communities, chiefly quaking aspen and paper birch. Occasionally stands of essentially pure white spruce develop following fires in the climax type. This occurs most frequently when the burned areas are relatively small and are surrounded by living trees of seed-bearing age. When the burns are extensive the light-seeded birch and quaking aspen are more likely to become established. Following fires, the fallen and standing snags constitute an increased fire hazard for 20 to 30 years.

As a result of repeated severe fires, areas formerly in white spruce may become essentially treeless, supporting herbaceous or shrub communities. Fireweed-grass and dwarf birch-willow may become so firmly established that it is difficult for forest-tree seedlings to become established. Natural reconversion of such lands to forest may require 100 to 200 years. Fires are most likely to result in replacement of white spruce forest by relatively permanent treeless communities at the upper altitudinal and latitudinal limits of forest growth.

Black spruce is a physiographic climax on poorly drained situations, in relatively flat valley bottoms, on flat to gently rolling land, and on cold slopes having a northern exposure. It forms pure stands of usually small, slow-growing trees. Permafrost is commonly encountered at the shallow depth of 12 to 18 inches. In the absence of fire, black spruce is a self-perpetuating type, reproducing by layering as well as seed. Fires in black spruce are often intense, killing the vegetation and consuming the forest floor. Even so, black spruce usually regenerates and another pure stand results. There is some evidence that severe fires in black spruce, repeated at short intervals, may lead to conversion to treeless communities such as sedge-rush-grass or low shrub. Re-entry of black spruce may then be a very slow process.

The forest soils of interior Alaska are shallow in both a developmental and a physiological sense. Excessive drainage may result in deficient soil moisture in coarse-textured soils. On the other hand, fine-textured soils may retain large amounts of water and become poorly aerated and cold. Organic matter tends to remain unincorporated in the mineral soil, for the most part resting on it as a mantle. Under old white spruce stands, and especially in the black spruce type, the forest floor may become as thick as 12 inches.

The degree to which the forest floor material is removed by fires varies with the intensity of the burn. It varies from slight charring of the uppermost litter to complete consumption down to mineral soil. In the recently burned areas examined, mineral soil was exposed over only 30 to 40 percent of the surface, even after fires so severe that all trees were killed. Practically none of the organic matter in the mineral soil was destroyed.

Partial or complete removal of the forest floor by burning leads to increased soil temperatures. In undisturbed condition, the moss and lichen cover is an effective insulator in the summer period. It is dry much of the time and effectively insulates the soil against the heat of the sun. Removal of this cover results in higher surface temperatures and a lower permafrost table. In general, the effects of fires on soil temperature are ecologically favorable. Moisture relations on steep southerly slopes are unfavorably affected by fires. In general, however, soil moisture relations do not appear to be greatly altered.

Soil texture and structure, so far as is known, are not changed by burning. Runoff from steep slopes is increased as a result of forest fires; the rate of infiltration apparently is reduced and the rate of overland flow is increased. Erosion by wind and water do not appear to be appreciably increased as a result of forest fires. The lack of extensive water erosion seems to be explained by the low total amount of precipitation, the normally low intensity of rainfall in individual storms, the long period each year that the soils are frozen and snow covered, and the rapidity of revegetation on burned lands.

Chemical changes in forest soils resulting from fires appear to be ecologically favorable. Acidity is decreased, and exchangeable calcium and potassium and readily available phosphorus are increased. Although the total nitrogen capital of the site is reduced by fires that consume the forest floor material, the amount of nitrogen available to plants appears to be increased.

Burning has an effect similar to fertilization. The nutrient capital in the forest floor, much of which may be regarded as a frozen asset,

is liberated in available form for use by the new plant growth. On the majority of forest sites, the productivity of the mineral soil body does not appear to be reduced by burning. From the standpoint of the soil alone, fires may have a favorable effect on certain properties.

Effects of forest fires on the hydrologic regime in Alaska cannot be stated with finality. Available evidence does point, however, to an increase in the normally high ratio of runoff to precipitation and to increased amplitude between high and low water stages. Watersheds having steep slopes, from which the vegetation has been removed by fire, have been reported to have very low minimum discharge rates and flashy runoff.

The wildlife of interior Alaska is one of the important renewable resources of the region. From it both the white population and natives derive very considerable economic benefits. It is a resource which has great attraction for hunters and for the even larger number of tourists who merely wish to see and photograph wildlife in its natural environment. Exceptions may occur, but in general the effect of uncontrolled forest fires on fur-bearing animals is unfavorable. This view is in agreement with those expressed repeatedly by many wildlife specialists.

The effect of uncontrolled forest fires on the moose population is still not entirely clear. In certain areas following fires there has been an increase of the moose population. It is only natural that this relation be interpreted in terms of cause and effect. However, it is doubtful that the relationship is a simple case of more browse, more moose. There are extensive areas in the interior which have been burned repeatedly and which support much browse but few moose. Moose in Alaska also have been moving westward and northward for over 75 years and this movement has taken the animals into areas where burning has not occurred. Thus the appearance and disappearance or the presence of large or sparse populations of moose are not to be explained simply and solely on the basis of fires or lack of fires. The possibilities of prescribed burning are recognized.

The effects of fires on caribou are generally agreed to be harmful or even disastrous. This animal normally lives in environments characterized by climax communities, tundra and forest-tundra transition. Fruticose lichens of the *Cladonia* group, together with certain beard lichens (such as species of *Usnea* and *Alectoria*) growing on trees, form the principal winter food of the caribou. These lichens are highly flammable when dry and readily susceptible to destruction by fire. Recovery is excessively slow. The length of time required for full recovery varies with the extent and intensity of the fires and site and microclimatic conditions, but an average of 40 to 50 years appears to be a conservative estimate.

Uncontrolled fires, sweeping over vast areas of the interior nearly every summer, place in jeopardy the future economic development of that portion of Alaska. The area involved is vast but the resources that can be used in perpetuity, even under wise management, are relatively modest—certainly there is no excess to be wasted. Potential production of cellulose on the better forest lands in the interior is considerable. On the 40 million acres of commercial or potentially commercial forest land, it is estimated that net annual growth is about 960 million cubic feet. Following a severe fire, a minimum of 100 years and an average period of perhaps 160 years must elapse before spruce sawlogs can again be obtained from the burned area.

The important wildlife resource and the rapidly developing tourist trade (whose potential can scarcely be judged at this time) are closely related to the forest resource. What damages the forests of the interior also damages these great economic assets.

The destiny of Alaska can be a great one only if her resources are wisely used. Widespread destruction of forest and other vegetation by fire, with all its harmful effects, cannot be judged wise use. The citizens of the Territory have a serious responsibility to be good stewards if the future Alaska is truly to become the "Great Land."

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# APPENDIX

## Check List of Plant Species Collected

### *Lichens*

*Alectoria jubata* (L.) Ach.
*A. nigricans* (Ach.) Nyl.
*A. pubescens* (L.) Howe
*Baeomyces placophyllus* Ach.
*Buellia papillata* (Sommerf.) Tuck.
*Cetraria cucullata* (Bell.) Ach.
*C. hiascens* (E. Fries) T. Fries
*C. islandica* (L.) Ach.
*C. juniperina* (L.) Ach.
*C. nivalis* (L.) Ach.
*C. richardsonii* (Hook.) Tuck.
*C. tilesii* Ach.
*Cladonia alpestris* (L.) Rabenh.
*C. alpestris* f. *aberrans* des Abbayes
*C. amaurocraea* (Floerke) Schaer.
*C. amaurocraea* f. *celotea* (Ach.) Vainio
*C. amaurocraea* f. *fasciculata* Kernst.
*C. amaurocraea* f. *oxyceras* (Ach.) Vainio
*C. bellidiflora* (Ach.) Schaer.
*C. cariosa* (Ach.) Spreng.
*C. cariosa* f. *corticata* Vainio
*C. cariosa* f. *cribrosa* (Wallr.) Vainio
*C. cariosa* f. *squamulosa* (Müll.-Arg.) Vainio
*C. cenotea* (Ach.) Schaer. f. *crossota* (Ach.) Nyl.
*C. chlorophaea* (Floerke) Spreng. f. *simplex* (Hoffm.) Arn.
*C. coccifera* (L.) Willd.
*C. coniocraea* (Floerke) Spreng. f. *stenoscypha* (Stuckenb.) Sandst.
*C. cornuta* (L.) Hoffm. f. *cylindrica* Schaer.
*C. cornuta* f. *scyphosa* Schaer.
*C. cornutoradiata* (Coem.) Sandst.
*C. crispata* (Ach.) Flot. var. *infundibulifera* (Schaer.) Vainio
*C. crispata* var. *virgata* (Ach.) Vainio
*C. deformis* (L.) Hoffm.
*C. degenerans* (Floerke) Spreng. f. *cladomorpha* (Ach.) Vainio
*C. degenerans* f. *euphorea* (Ach.) Floerke
*C. degenerans* f. *gracilescens* Floerke
*C. ecmocyna* (Ach.) Nyl. var. *nigripes* (Nyl.) Evans
*C. furcata* (Huds.) Schrad. var. *racemosa* (Hoffm.) Floerke
*C. furcata* var. *racemosa* f. *corymbosa* (Ach.) Vainio
*C. gonecha* (Ach.) Asahina
*C. gracilis* (L.) Willd. var. *chordalis* (Floerke) Schaer.
*C. gracilis* var. *chordalis* f. *leucochlorea* Floerke
*C. gracilis* var. *chordalis* f. *platydactyla* (Wallr.) Vainio
*C. gracilis* var. *dilatata* (Hoffm.) Vainio
*C. gracilis* var. *elongata* (Jacq.) E. Fries
*C. gracilis* var. *elongata* f. *laontera* (Del.) Arn.
*C. lepidota* Nyl.
*C. mitis* Sandst.
*C. multiformis* Merrill f. *finkii* (Vainio) Evans
*C. multiformis* f. *simulata* Robbins
*C. multiformis* f. *subascypha* (Vainio) Evans
*C. pleurota* (Floerke) Schaer. f. *extensa* (Ach.) Sandst.
*C. pseudorangiformis* Asahina
*C. pyxidata* (L.) Hoffm. var. *neglecta* (Floerke) Mass.
*C. pyxidata* var. *pocillum* (Ach.) Flot.
*C. rangiferina* (L.) Web.
*C. rangiferina* f. *stygia* E. Fries
*C. scabriuscula* (Del.) Leight.
*C. scabriuscula* f. *adspersa* (Floerke) Sandst.
*C. scabriuscula* f. *sublevis* Sandst.
*C. scabriuscula* f. *surrecta* (Floerke) Sandst.
*C. squamosa* (Scop.) Hoffm. f. *muricella* (Del.) Vainio
*C. squamosa* (Scop.) Hoffm. f. *turfacea* Rehm.
*C. sylvatica* (L.) Hoffm.
*C. uncialis* (L.) Web.
*C. verticillata* (Hoffm.) Schaer. f. *aggregata* (Del.) Oliv.
*C. verticillata* f. *evoluta* (T. Fries) Stein.
*Dactylina arctica* (Hook.) Nyl.
*Diploschistes scruposus* (Schreb.) Norm.
*Dufourea madreporiformis* (Wulf.) Ach.
*Ephebe solida* Born.
*Evernia mesomorpha* Nyl.
*Fulgensia bracteata* (Hoffm.) Räs.
*Haematomma ventosum* (L.) Mass. var. *lapponicum* (Räs.) Lynge
*Icmadophila ericetorum* (L.) Zahlbr.
*Lecanora subfuscata* Magn.
*Lecidea rubiformis* Wahl.
*Lobaria linita* (Ach.) Rabh.
*L. pulmonaria* (L.) Hoffm.
*Nephroma arcticum* (L.) Torss.
*N. expallidum* Nyl.

### *Lichens*—Continued

*Ochrolechia frigida* (Swartz) Lynge
*Parmelia alpicola* T. Fries
*P. omphalodes* (L.) Ach.
*P. sulcata* Tayl.
*P. vittata* (Ach.) Nyl.
*Parmeliopsis hyperopta* (Ach.) Vainio
*Peltigera aphthosa* (L.) Willd. var. *aphthosa*
*P. aphthosa* var. *variolosa* (Mass.) Thoms.
*P. canina* (L.) Willd.
*P. canina* var. *rufescens* (Weis.) Mudd
*P. canina* var. *spuria* (Ach.) Schaer.
*P. canina* var. *spuria* f. *sorediata* Schaer.
*P. malacea* (Ach.) Funck
*P. membranacea* (Ach.) Nyl. emend. Thoms.
*P. pulverulenta* (Tayl.) Nyl.
*Ramalina farinacea* (L.) E. Fries
*Stereocaulon paschale* (L.) Hoffm.
*S. paschale* var. *alpinum* (Laur.) Mudd
*S. paschale* var. *alpinum* f. *gracilentum* (T. Fries) M. Lamb
*S. paschale* var. *grande* H. Magn.
*S. paschale* var. *grande* f. *velutinum* (Frey) M. Lamb
*S. tomentosum* E. Fries
*S. tomentosum* var. *alpestre* Flot.
*S. vesuvianum* Pers. var. *arcticum* (Lynge) M. Lamb
*Thamnolia vermicularis* (Swartz) Ach.
*Usnea comosa* (Ach.) Röhl. ssp. *comosa*
*U. scabiosa* Mot.

### *Mosses*

*Aulacomnium palustre* (Web. & Mohr) Schwaegr.
*A. turgidum* (Wahl.) Schwaegr.
*Brachythecium albicans* (Hedw.) BSG.
*B. salebrosum* (Web. & Mohr) BSG.
*Bryum caespiticium* Hedw.
*B. cuspidatum* (BSG.) Schimp.
*B. turbinatum* (Hedw.) Schwaegr.
*B. uliginosum* (Brid.) BSG.
*Calliergon stramineum* (Brid.) Kindb.
*Camptothecium lutescens* (Hedw.) BSG.
*Campylium stellatum* (Hedw.) Lange & C. Jens.
*Ceratodon purpureus* (Hedw.) Brid.
*Climacium dendroides* (Hedw.) Web. & Mohr
*Cratoneuron filicinum* (Hedw.) Roth
*Dichodontium pellucidum* (Hedw.) Schimp.
*Dicranella grevilleana* (Brid.) Schimp.
*Dicranum bergeri* Bland.
*D. drummondii* C. Müll.
*D. elongatum* Schleich.
*D. fragilifolium* Lindb.
*D. fuscescens* Turn.
*D. majus* Smith
*D. muhlenbeckii* BSG.
*D. strictum* Schleich.
*Distichium capillaceum* (Hedw.) BSG.
*Ditrichum flexicaule* (Schwaegr.) Hampe
*Drepanocladus aduncus* (Hedw.) Warnst.
*D. fluitans* (Hedw.) Warnst
*D. uncinatus* (Hedw.) Warnst.
*Eurhynchium praelongum* (Hedw.) Bryhn.
*E. stubstrigosum* Kindb.
*Hylocomium splendens* (Hedw.) BSG.
*Hypnum crista-castrensis* Hedw. (syn. *Ptilium crista-castrensis* (Hedw.) De Not.).
*H. dieckii* Ren. & Card.
*H. imponens* Hedw.
*H. lindbergii* Mitt.
*H. revolutum* (Mitt.) Lindb.
*Leptobryum pyriforme* (Hedw.) Schimp.
*Meesia uliginosa* Hedw.
*Mnium affine* Bland.
*M. spinulosum* Bruch & Schimp.
*Oncophorus wahlenbergii* Brid.
*Paludella squarrosa* (Hedw.) Brid.
*Philonotis fontana* (Hedw.) Brid.
*Plagiothecium denticulatum* (L.) Br. Sch.
*Pleurozium schreberi* (Brid.) Mitt.
*Pohlia nutans* (Hedw.) Lindb.
*P. wahlenbergii* (Web. & Mohr) Andrews
*Polytrichum commune* Hedw.
*P. juniperinum* Hedw.
*P. piliferum* Hedw.
*P. strictum* Brid.
*Rhacomitrium canescens* Brid.
*R. lanuginosum* (Hedw.) Brid.
*Rhytidium rugosum* (Hedw.) Kindb.
*Rhytidiadelphus triquetrus* (Hedw.) Warnst.
*Sphagnum capillaceum* (Weiss) Schrank
*S. capillaceum* var. *tenellum* (Schimp.) Andrews
*S. fuscum* (Schimp.) Klinggr.
*S. girgensohnii* Russ.
*S. plumulosum* Röll
*S. rubellum* Wils.
*S. teres* (Schimp.) Ångstr.
*Tetraplodon mnioides* (Hedw.) BSG.
*Thuidium abietinum* (Brid.) BSG.
*T. delicatulum* (Hedw.) Mitt.
*Timmia austriaca* Hedw.
*Tomenthypnum nitens* (Hedw.) Loeske
*Tortella fragilis* (Hook. & Wils.) Limpr.

### *Liverworts*

*Lophozia porphyroleuca* (Nees) Schiffn.
*Marchantia polymorpha* L.
*Preissia quadrata* (Scop.) Nees
*Ptilidium ciliare* (L.) Nees

### Grasses

*Agropyron latiglume* (Scribn. & Smith) Rydb.
*A. subsecundum* (Link) Hitchc.—Bearded wheatgrass
*A. trachycaulum* (Link) Malte—Slender wheatgrass
*Agrostis scabra* Willd.—Bentgrass
*Alopecurus aequalis* Sobol.—Shortawn foxtail
*A. alpinus* J. E. Smith—Alpine foxtail
*Arctagrostis latifolia* (R. Br.) Griseb.
*Bromus arcticus* Shear—Arctic brome
*B. pumpellianus* Scribn.—Pumpelly brome
*B. pumpellianus* var. *villosissimus* Hult.
*Calamagrostis canadensis* (Michx.) Beauv.—Bluejoint reedgrass
*C. inexpansa* A. Gray—Northern reedgrass
*C. neglecta* (Ehrh.) Gaertn., Mey., & Schreb.—Slimstem reedgrass
*C. purpurascens* R. Br.—Purple pinegrass
*Deschampsia atropurpurea* (Wahl.) Scheele—Mountain hairgrass
*D. caespitosa* (L.) Beauv.—Tufted hairgrass
*Elymus innovatus* Beal—Fuzzyspike wildrye
*Festuca altaica* Trin.—Altai fescue
*F. ovina* L.—Sheep fescue
*F. ovina* var. *brachyphylla* (Schult.) Piper—Alpine sheep fescue
*F. rubra* L.—Red fescue
*F. rubra* var. *lanuginosa* Mert. & Koch—Hairyscale red fescue
*Hierochloë alpina* (Swartz) Roem. & Schult.—Alpine sweetgrass
*H. odorata* (L.) Beauv.—Sweetgrass
*Hordeum jubatum* L.—Foxtail barley
*Phleum alpinum* L.—Alpine timothy
*Poa alpina* L.—Alpine bluegrass
*P. arctica* R. Br.—Arctic bluegrass
*P. glauca* Vahl—Greenland bluegrass
*P. interior* Rydb.—Inland bluegrass
*P. paucispicula* Scribn. & Merr.—Alaska bluegrass
*P. pratensis* L.—Kentucky bluegrass
*P. stenantha* Trin.—Trinius bluegrass
*Trisetum spicatum* (L.) Richt.—Spike trisetum

### Grasslike Plants

*Carex aquatilis* Wahl.—Water sedge
*C. bigelowii* Torr.—Bigelow sedge
*C. canescens* L.
*C. capillaris* L.
*C. concinna* R. Br.
*C. diandra* Schrank
*C. disperma* Dew.
*C. eburnea* Boott
*C. garberi* Fern. var. *bifaria* Fern.
*C. loliacea* L.—Ryegrass sedge
*C. lugens* Holm
*C. macrochaeta* C. A. Meyer
*C. maritima* Gunn. (syn. *C. incurva* Lightf.)
*C. media* R. Br.



*C. membranacea* Hook.
*C. mertensii* Prescott—Mertens sedge
*C. podocarpa* R. Br.
*C. praticola* Rydb.
*C. rossii* Boott—Ross sedge
*C. rostrata* Stokes—Beaked sedge
*C. scirpoidea* Michx.
*C. supina* Willd. ssp. *spaniocarpa* (Steud.) Hult.
*C. vaginata* Tausch.
*Eleocharis palustris* (L.) Roem. & Schult.—Common spikesedge
*Eriophorum brachyantherum* Trautv.
*E. scheuchzeri* Hoppe—Scheuchzer cottonsedge
*E. vaginatum* L.—Sheathed cottonsedge
*Juncus alpinus* Vill.—Alpine rush
*J. castaneus* J. E. Smith
*J. drummondii* E. Meyer
*Luzula multiflora* (Retz.) Lejeune
*L. parviflora* (Ehrh.) Desv.—Millet woodrush
*L. rufescens* Fisch.
*L. sudetica* (Willd.) DC. (syn. *L. campestris* (L.) DC. var. *alpina* Gaudin)—Sudetic woodrush
*L. wahlenbergii* Rupr.—Wahlenberg woodrush
*Scirpus cespitosus* L. var. *callosus* Bigel.—Callous deerhair bulrush
*Triglochin palustris* L.—Arrow podgrass

### Forbs

*Achillea borealis* Bong.—Arctic yarrow
*Aconitum delphinifolium* DC.
*A. delphinifolium* ssp. *paradoxum* (Reichenb.) Hult.
*A. maximum* Pall.
*Actaea arguta* Nutt.—Western baneberry
*Androsace lehmanniana* Spreng.—Lehmann rockjasmine
*A. septentrionalis* L.—Northern rockjasmine
*Anemone narcissiflora* L. ssp. *interior* Hult.—Narcissus anemone
*A. richardsonii* Hook.—Richardson anemone
*Antennaria monocephala* DC.
*A. nitida* Greene
*A. oxyphylla* Greene
*Aquilegia brevistyla* Hook.—Yukon columbine
*A. formosa* Fisch.—Sitka columbine
*Arabis hirsuta* (L.) Scop. var. *pycnocarpa* (M. Hopkins) Rollins—Common hairy rockcress
*A. holboellii* Hornem.—Holboell rockcress
*A. holboellii* var. *retrofracta* (Graham) Rydb.
*A. lyrata* L. ssp. *kamchatica* (Fisch.) Hult.
*Arenaria lateriflora* L.—Bluntleaf sandwort
*A. macrocarpa* Pursh—Long-podded sandwort
*A. obtusiloba* (Rydb.) Fern.—Alpine sandwort
*A. rubella* (Wahl.) J. E. Smith
*A. stricta* (Swartz) Michx.—Rock sandwort
*Arnica latifolia* Bong.—Broadleaf arnica
*A. louiseana* Farr ssp. *frigida* (Meyer) Maguire

*Forbs*—Continued

*Artemisia arctica* Less.—Arctic wormwood
*Aruncus dioicus* (Walt.) Fern.—Sylvan goatsbeard
*Aster sibericus* L.—Siberian aster
*Astragalus alpinus* L.—Alpine milkvetch
*A. americanus* (Hook.) M. E. Jones—Arctic milkvetch
*A. tananaicus* Hult.—Tanana milkvetch
*A. yukonis* M. E. Jones—Yukon milkvetch
*Athyrium filix-femina* (L.) Roth ssp. *cyclosorum* (Rupr.) C. Chr.—Ladyfern
*Boschniakia rossica* (Cham. & Schlecht.) B. Fedtsch.—Poque
*Boykinia richardsonii* (Hook.) Rothr. (syn. *Therofon richardsonii* (Hook.) O. Kuntze)—Richardson boykinia
*Bupleurum americanum* Coult. & Rose—Thorowax
*Calla palustris* L.—Wild calla
*Campanula alaskana* (A. Gray) Wight—Alaska bellflower
*C. lasiocarpa* Cham.—Behring bellflower
*Cardamine bellidifolia* L.—Daisyleaf bittercress
*C. umbellata* Greene—Umbel-flowered bittercress
*Castilleja hyperborea* Pennell—Paintedcup
*C. pallida* (L.) Kunth ssp. *caudata* Pennell
*C. pallida* ssp. *mexiae* (Eastw.) Pennell
*Cerastium arvense* L.—Starry cerastium
*Chenopodium capitatum* (L.) Aschers.—Blite goosefoot
*Chrysanthemum leucanthemum* L. var. *pinnatifidum* Lecoq & Lamotte—Field oxeyedaisy
*Chrysosplenium tetrandrum* (Lund) T. Fries—Fourstamen goldsaxifrage
*Cicuta mackenzieana* Raup—Mackenzie waterhemlock
*Circaea alpina* L.—Alpine circaea
*Claytonia sarmentosa* C. A. Mey.—Alaska springbeauty
*Comandra livida* Richards.—Northern comandra
*Conioselinum cnidiifolium* (Turcz.) Pors.—Dawson hemlockparsley
*Corallorhiza mertensiana* Bong.—Pacific coralroot
*C. trifida* Chatelain—Early coralroot
*Corydalis sempervirens* (L.) Pers.—Pale corydalis
*Crepis elegans* Hook.—Hawksbeard
*C. nana* Richards.—Tiny hawksbeard
*Cryptogramma acrostichoides* R. Br.—American rockbrake
*C. stelleri* (Gmel.) Prantl—Slender rockbrake
*Cypripedium passerinum* Richards.—Canada ladyslipper
*Cystopteris fragilis* (L.) Bernh.—Brittle bladderfern
*Delphinium brownii* Rydb.—Browns larkspur
*D. glaucum* Watson—Sierra larkspur
*Descurainia sophioides* (Fisch.) O. E. Schultz—Northern tansymustard
*Diapensia lapponica* L. ssp. *obovata* (Fr. Schmidt) Hult.—Arctic diapensia
*Draba aurea* Vahl—Golden draba
*D. borealis* DC.—Northern draba
*Drosera rotundifolia* L.—Roundleaf sundew
*Dryopteris austriaca* (Jacq.) Woynar, Schinz, & Thellung—Spreading woodfern
*D. disjuncta* (Ledeb.) C. V. Mort.—Oakfern
*D. fragrans* (L.) Schott—Fragrant woodfern
*Epilobium adenocaulon* Hausskn.—Sticky willowweed
*E. anagallidifolium* Lam.
*E. angustifolium* L.—Fireweed
*E. latifolium* L.—Red willowweed
*E. leptocarpum* Hausskn.
*E. palustre* L.
*Equisetum arvense* L.—Field horsetail
*E. pratense* Ehrh.—Meadow horsetail
*E. scirpoides* Michx.—Sedgelike horsetail
*E. sylvaticum* L.—Sylvan horsetail
*E. variegatum* Schleich.—Variegated horsetail
*Erigeron acris* L. var. *asteroides* (Andrz.) DC.—Bitter fleabane
*E. lonchophyllus* Hook.—Spearleaf fleabane
*E. peregrinus* (Pursh) Greene—Peregrine fleabane
*E. purpuratus* Greene—Fleabane
*Fritillaria camschatcensis* (L.) Ker-Gawl.—Kamchatka fritillary
*Galium boreale* L.—Northern bedstraw
*G. triflorum* Michx.—Sweetscented bedstraw
*Gentiana acuta* Michx. var. *plebeja* (Cham.) Wettst.—Northern gentian
*G. detonsa* Rottb.—Gentian
*G. glauca* Pall.—Bluegreen gentian
*G. propinqua* Richards.—Gentian
*Geranium erianthum* DC.—Geranium
*Geum macrophyllum* Willd.—Largeleaf avens
*G. rossii* (R. Br.) Sér.—Ross avens
*Goodyera repens* (L.) R. Br. var. *ophioides* Fern.—Creeping rattlesnake-plantain
*Habenaria dilatata* (Pursh) Hook.—White bogorchid
*H. hyperborea* (L.) R. Br.—Northern green habenaria
*H. obtusata* (Pursh) Richards.—Bluntleaf habenaria
*Hedysarum alpinum* L. ssp. *americanum* (Michx.) Fedtsch.—American sweetvetch
*H. mackenzii* Richards.—Mackenzie sweetvetch
*Heracleum lanatum* Michx.—Common cowparsnip
*Heuchera glabra* Willd.—Alumroot
*Hieracium triste* Willd.—Hawkweed
*Hippuris vulgaris* L.—Marestail
*Lathyrus palustris* L. ssp. *pilosus* (Cham.) Hult.—Hairy marsh peavine
*Leptarrhena pyrolifolia* (D. Don) Sér.—Leather-leaf saxifrage
*Lesquerella arctica* (Wormskj.) S. Wats.—Arctic bladderpod
*Linnaea borealis* L. var. *americana* (Forbes) Rehd.—American twinflower
*Listera cordata* (L.) R. Br.—Northern listera
*Lupinus arcticus* S. Wats.—Arctic lupine
*L. nootkatensis* Donn—Nootka lupine
*L. polyphyllus* Lindl.—Washington lupine
*Lycopodium alpinum* L.—Alpine clubmoss
*L. annotinum* L.—Bristly clubmoss
*L. clavatum* L.—Runningpine

*L. clavatum* var. *monostachyon* Grev. & Hook.
*L. complanatum* L.—Groundcedar
*L. selago* L.—Fir clubmoss
*Melandrium taimyrense* A. Tolmatchev
*Menyanthes trifoliata* L.—Common bogbean
*Mertensia paniculata* (Ait.) G. Don—Panicle bluebells
*Mimulus guttatus* DC.—Common monkeyflower
*Mitella pentandra* Hook.—Fivestamen miterwort
*Moneses uniflora* (L.) A. Gray—Woodnymph
*Myosotis alpestris* F. W. Schmidt—Alpine forgetmenot
*Myriophyllum exalbescens* Fern.—Parrotfeather
*Nuphar polysepalum* Engelm.—Rocky Mountain cowlily
*Orchis rotundifolia* Banks—Roundleaf orchis
*Osmorhiza obtusa* (Coult. & Rose) Fern.—Bluntseed sweetroot
*Oxyria digyna* (L.) Hill—Alpine mountain-sorrel
*Oxytropis campestris* (L.) DC.—Plains crazyweed
*O. campestris* var. *varians* (Rydb.) Barneby—Variable plains crazyweed
*O. maydelliana* Trautv.—Maydell crazyweed
*O. nigrescens* (Pall.) Fisch.—Blackish crazyweed
*O. scammaniana* Hult.—Scamman crazyweed
*O. splendens* Dougl.—Showy crazyweed
*O. viscida* Nutt. var. *subsucculenta* (Hook.) Barneby—Yellowhair crazyweed
*Parnassia kotzebuei* Cham. & Schlecht.—Kotzebue parnassia
*P. palustris* L.—Wideworld parnassia
*Pedicularis capitata* Adams—Pedicularis
*P. labradorica* Wirsing—Labrador pedicularis
*P. lanata* Cham. & Schlecht.—Woollyspike pedicularis
*P. parviflora* J. E. Smith—Smallflower pedicularis
*P. sudetica* Willd.—Sudetic pedicularis
*P. verticillata* L.—Whorled pedicularis
*Petasites frigidus* (L.) E. Fries—Arctic butterbur ("sweet coltsfoot")
*P. sagittatus* (Pursh) A. Gray—Arrowleaf butterbur ("sweet coltsfoot")
*Pinguicula villosa* L.—Hairy butterwort
*Polemonium acutiflorum* Willd.
*P. boreale* Adams—Arctic polemonium
*P. caeruleum* L. ssp. *villosum* Brand.—Greekvalerian polemonium
*P. pulcherrimum* Hook.—Skunkleaf polemonium
*Polygonum alaskanum* (Small) Wight—Alaska knotweed
*P. bistorta* L. ssp. *plumosum* (Small) Hult.—Feathery European bistort
*P. viviparum* L.—Viviparous bistort
*Potentilla norvegica* L. ssp. *monspeliensis* (L.) Aschers. & Graebn.—Montpelier cinquefoil
*P. palustris* (L.) Scop.—Marsh cinquefoil
*P. pensylvanica* L.—Pennsylvania cinquefoil
*P. pensylvanica* var. *strigosa* Pursh
*Primula cuneifolia* Ledeb. ssp. *saxifragifolia* (Lehm.) Hult.—Saxifrage primrose
*Pulsatilla ludoviciana* Heller—American pasqueflower
*Pyrola asarifolia* Michx. var. *incarnata* (Fisch.) Fern.—Alpine pyrola
*P. grandiflora* Radius—Bigflower pyrola
*P. minor* L.—Snowline pyrola
*P. secunda* L.—Sidebells pyrola
*P. virens* Schweigger (syn. *P. chlorantha* Swartz)—Green pyrola
*Ranunculus cymbalaria* Pursh—Shore buttercup
*R. occidentalis* Nutt.—Western buttercup
*R. repens* L.—Creeping buttercup
*R. trichophyllus* Chaix—Hairleaf watercrowfoot
*Rorippa palustris* (L.) Besser var. *hispida* (Desv.) Rydb.—Hairy bog marshcress
*Rumex arcticus* Trautv.—Arctic dock
*Sanguisorba menziesii* Rydb.—Menzies burnet
*S. stipulata* Raf.
*Saussurea angustifolia* (Willd.) DC.—Narrowleaf saussurea
*Saxifraga bronchialis* L. ssp. *funstonii* (Small) Hult.—Funston saxifrage
*S. eschscholtzii* Sternb.—Eschscholtz saxifrage
*S. hieracifolia* Waldst. & Kit.—Hawkweed saxifrage
*S. oppositifolia* L.—Twinleaf saxifrage
*S. punctata* L. ssp. *pacifica* Hult.—Dotted saxifrage
*S. rivularis* L.—Streambank saxifrage
*S. tricuspidata* Rottb.—Threebristle saxifrage
*Sedum rosea* (L.) Scop. ssp. *integrifolium* (Raf.) Hult.—Roseroot stonecrop
*Selaginella sibirica* (Milde) Hieron.—Siberian selaginella
*Senecio atropurpureus* (Ledeb.) Fedtsch. ssp. *frigidus* (Richards.) Hult.—Arctic groundsel
*S. congestus* (R. Br.) DC. var. *palustris* (L.) Fern.—Swamp groundsel
*S. integerrimus* Nutt.—Lambstongue groundsel
*S. pauciflorus* Pursh
*S. pauperculus* Michx.—Balsam groundsel
*S. resedifolius* Less.—Mignonette groundsel
*Silene acaulis* L.—Moss silene
*S. williamsii* Britt.—Williams silene
*Smilacina stellata* (L.) Desf.—Starry solomonplume
*Solidago multiradiata* Ait.
*S. oreophila* Rydb.
*Sparganium angustifolium* Michx.—Narrowleaf burreed
*Stellaria calycantha* (Ledeb.) Bong.—Bongard starwort
*S. ciliatosepala* Trautv.
*S. longipes* Goldie—Longstalk starwort
*Streptopus amplexifolius* (L.) DC.—Claspleaf twistedstalk
*Swertia perennis* L.—Alpinebog swertia
*Taraxacum alaskanum* Rydb.—Alaska dandelion
*T. lapponicum* Kihlm.—Lapland dandelion
*Thalictrum sparsiflorum* Turcz.—Meadowrue
*Tofieldia coccinea* Richards.—Purple tofieldia
*T. pusilla* (Michx.) Pers.—Small tofieldia
*Torularia humilis* (C. A. Mey.) O. E. Schulz—Northern rockcress
*Trientalis europaea* L. ssp. *arctica* (Fisch.) Hult.—Arctic starflower
*Typha latifolia* L.—Common cattail

### *Forbes*—Continued

*Urtica lyallii* S. Wats.—Lyall nettle
*Valeriana capitata* Pall.
*V. capitata* var. *bracteosa* (Britt.) Hult.
*Veronica wormskjoldii* Roem. & Schult.—Wormskjold speedwell
*Viola adunca* J. E. Smith—Hook violet
*V. epipsila* Ledeb. ssp. *repens* (Turcz.) W. Bckr.—Creeping violet
*V. renifolia* Gray var. *brainerdii* (Greene) Fern.—Brainerd violet
*Zigadenus elegans* Pursh—Mountain deathcamas

### *Trees and Shrubs*

*Alnus crispa* (Ait.) Pursh—American green alder
*A. sinuata* (Reg.) Rydb.—Sitka alder
*A. tenuifolia* Nutt.—Thinleaf alder
*Amelanchier alnifolia* Nutt.—Saskatoon serviceberry
*A. florida* Lindl.—Pacific serviceberry
*Andromeda polifolia* L.—Bogrosemary andromeda
*Arctostaphylos alpina* (L.) Spreng. ssp. *rubra* Hult.—Redalpine bearberry
*A. uva-ursi* (L.) Spreng.—Bearberry
*Artemisia alaskana* Rydb.—Alaska sagebrush
*A. borealis* Pall.—Northern wormwood
*A. dracunculus* L.—Tarragon
*A. frigida* Willd.—Fringed sagebrush
*A. tilesii* Ledeb. var. *elatior* Torr. & A. Gray
*Betula* ×*eastwoodae* Sarg.—Yukon birch
*B. glandulosa* Michx.—Bog birch
*B. nana* L. ssp. *exilis* (Sukatch.) Hult.—Dwarf arctic birch
*B. papyrifera* Marsh. var. *humilis* (Reg.) Fern. & Raup—Alaska paper birch
*B. papyrifera* Marsh. var. *kenaica* (W. H. Evans) A. Henry—Kenai paper birch
*Cassiope stelleriana* (Pall.) DC.—Starry cassiope
*C. tetragona* (L.) D. Don—Firemoss cassiope
*Cornus canadensis* L.—Bunchberry dogwood
*C. stolonifera* Michx.—Redosier dogwood
*Dryas alaskensis* Porsild—Alaska dryad
*D. drummondii* Richards.—Drummond dryad
*D. hookeriana* Juz.—Hooker dryad
*D. octopetala* L.—Mt. Washington dryad
*D. punctata* Juz.
*Elaeagnus commutata* Bernh.—Silverberry
*Empetrum nigrum* L.—Black crowberry
*Juniperus communis* L. var. *saxatilis* Pall.—Mountain common juniper
*J. horizontalis* Moench—Creeping juniper
*Larix laricina* (Du Roi) K. Koch—Eastern larch
*Ledum palustre* L. ssp. *decumbens* (Ait.) Hult.—Sprawling crystaltea ledum
*L. palustre* ssp. *groenlandicum* (Oeder) Hult.—Labrador-tea ledum
*Loiseleuria procumbens* (L.) Desv.—Alpine-azalea
*Luetkea pectinata* (Pursh) Kuntze—Luetkea
*Menziesia ferruginea* J. E. Smith—Rusty menziesia
*Oplopanax horridus* (J. E. Smith) Miq.—American devilsclub
*Oxycoccus microcarpus* Turcz.—Small cranberry
*Picea glauca* (Moench) Voss—White spruce
*P. glauca* var. *porsildi* Raup—Porsild spruce
*P.* ×*lutzii* Little—Lutz spruce
*P. mariana* (Mill.) B. S. P.—Black spruce
*P. sitchensis* (Bong.) Carr.—Sitka spruce
*Populus balsamifera* L.—Balsam poplar
*P. tremuloides* Michx.—Quaking aspen
*P. trichocarpa* Torr. & A. Gray—Black cottonwood
*Potentilla fruticosa* L.—Bush cinquefoil
*Rhododendron lapponicum* (L.) Wahlenb.—Lapland rhododendron
*Ribes hudsonianum* Richards.—Hudson Bay currant
*R. lacustre* (Pers.) Poir.—Prickly currant
*R. triste* Pall.—American red currant
*Rosa acicularis* Lindl.—Prickly rose
*Rubus alaskensis* Bailey—Alaska bramble
*R. chamaemorus* L.—Cloudberry
*R. idaeus* L. var. *strigosus* (Michx.) Maxim.—American red raspberry
*R. pedatus* J. E. Smith—Fiveleaf bramble
*R. stellatus* J. E. Smith—Nagoonberry
*Salix alaxensis* (Anderss.) Cov.—Feltleaf willow
*S. alaxensis* var. *longistylis* (Rydb.) Schneid.—Bluetwig feltleaf willow
*S. anglorum* Cham.—Northland willow
*S. arbusculoides* Anderss.—Littletree willow
*S. arbusculoides* var. *glabra* Anderss.—Smooth littletree willow
*S. arctica* Pall.—Arctic willow
*S. arctica* var. *obcordata* Ball—Bluntleaf arctic willow
*S. barclayi* Anderss.—Barclay willow
*S. barclayi* var. *angustifolia* Anderss.
*S. barclayi* var. *hebecarpa* Anderss.
*S. barclayi* var. *rotundifolia* Anderss.
*S. bebbiana* Sarg.—Bebb willow
*S. bebbiana* var. *perrostrata* (Rydb.) Schneid.—Smooth Bebb willow
*S. commutata* Bebb—Undergreen willow
*S. glauca* L.—Grayleaf willow
*S. glauca* var. *acutifolia* (Hook.) Schneid.
*S. glauca* var. *aliceae* Ball
*S. myrtillifolia* Anderss.—Blueberry willow
*S. pseudomonticola* Ball—Park willow
*S. pulchra* Cham.—Diamondleaf willow
*S. pulchra* var. *palmeri* Ball—Palmer diamondleaf willow
*S. pulchra* var. *yukonensis* Schneid.—Yukon diamondleaf willow
*S. reticulata* L.—Netleaf willow
*S. reticulata* var. *subrotundata* Sér.—Round netleaf willow
*S. richardsonii* Hook.—Richardson willow
*S. rotundifolia* Trautv.—Least willow
*S. scouleriana* Barr.—Scouler willow
*S. setchelliana* Ball—Setchell willow

### *Trees and Shrubs*—Continued

*S. sitchensis* Sanson—Sitka willow
*S. walpolei* (Cov. & Ball) Ball—Walpole willow
*Sambucus callicarpa* Greene—Pacific red elder
*Shepherdia canadensis* (L.) Nutt.—Russet buffaloberry
*Sorbus scopulina* Greene—Greenes mountain-ash
*Spiraea beauverdiana* Schneid.—Beauverd spirea
*Tsuga mertensiana* (Bong.) Sarg.—Mountain hemlock
*Vaccinium cespitosum* Michx.—Dwarf blueberry
*V. uliginosum* L.—Bog bilberry
*V. vitis-idaea* L.—Cowberry
*Viburnum edule* (Michx.) Raf. (syn. *Viburnum pauciflorum* La Pylaie)—Mooseberry viburnum

## Soil Analyses

Soil samples were collected from several of the plots on the Kenai Peninsula in 1949 and subjected to laboratory analyses for various properties (tables 10–26). Mechanical analyses followed the method of Bouyoucos (*17*). The data are presented in terms of both the American and the International systems. Other analyses followed the methods outlined by Peech et al. (*112*).

Soil horizons were designated by Arabic numerals, except as indicated, rather than by the commonly employed A, B, C terminology. This was done because the genetic relations of the horizons were not clear. In all cases the $1_0$ horizon represented unincorporated organic matter that frequently was not separable into L, F, and H layers. Horizon 1 usually corresponded approximately to an $A_2$ horizon and the deepest layer represented in a given profile usually corresponded approximately to the C horizon. In several profiles from recently burned areas a supplementary set of samples were collected. In the records these are designated by Roman numerals. Layer I represented the uppermost mineral soil to the base of the $A_2$ horizon; layer II, the upper part of layer I; layer III, the lower part of layer I; and layer IV, the upper part of the B horizon.

TABLE 10.—*Mechanical analysis of soil, Plot P49-1* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–9.02 | 0.02–0.002 | <0.002 |
| 1 | 0.10 | 1.72 | 9.44 | 15.20 | 9.74 | 50.32 | 13.48 | 15.72 | 16.15 | 44.03 | 26.34 | 13.48 |
| 2 | .16 | .42 | 3.45 | 12.38 | 12.90 | 59.97 | 10.72 | 16.40 | 7.42 | 48.44 | 33.42 | 10.72 |
| 3 | .06 | .23 | 3.00 | 13.57 | 11.44 | 58.90 | 12.80 | 16.15 | 6.68 | 51.36 | 29.16 | 12.80 |
| 4 | .39 | .68 | 4.87 | 9.03 | 9.94 | 65.58 | 9.51 | 15.92 | 9.08 | 53.71 | 27.70 | 9.51 |
| 5 | .07 | .21 | 1.63 | 4.54 | 9.12 | 74.93 | 9.50 | 15.90 | 3.24 | 57.52 | 29.74 | 9.50 |
| 6 | 1.10 | 1.83 | 10.79 | 19.71 | 9.03 | 42.10 | 15.44 | 19.90 | 21.42 | 44.05 | 19.09 | 15.44 |

[1] For information on the forest cover on this plot, see table 8.

TABLE 11.—*Mechanical analysis of soil, Plot P49-5* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.10 | 0.28 | 3.58 | 13.65 | 10.47 | 59.38 | 12.54 | 16.23 | 7.48 | 46.49 | 33.49 | 12.54 |
| 2 | .05 | .33 | 3.33 | 9.30 | 13.60 | 63.58 | 9.81 | 15.78 | 6.22 | 56.65 | 27.30 | 9.81 |
| 3 | .11 | .15 | 2.10 | 5.70 | 8.03 | 69.12 | 14.79 | 19.58 | 4.12 | 49.22 | 31.87 | 14.79 |
| 4 | .11 | .25 | .45 | 1.60 | 10.30 | 79.01 | 8.28 | 8.88 | 1.06 | 67.85 | 22.81 | 8.28 |
| 5 | 4.30 | 6.33 | 14.43 | 16.89 | 11.43 | 31.30 | 15.32 | 18.95 | 30.97 | 37.98 | 15.73 | 15.32 |

[1] For information on the forest cover on this plot, see table 8.

TABLE 12.—*Mechanical analysis of soil, Plot P49-9* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.44 | 0.65 | 6.48 | 14.89 | 8.58 | 57.15 | 11.81 | 15.48 | 12.62 | 45.42 | 30.15 | 11.81 |
| 2 | 1.42 | 1.93 | 6.44 | 13.53 | 10.46 | 54.09 | 12.13 | 16.94 | 13.92 | 46.14 | 27.81 | 12.13 |
| 3 | .54 | .71 | 4.89 | 12.60 | 9.03 | 60.28 | 11.95 | 17.72 | 10.35 | 47.19 | 30.51 | 11.95 |
| 4 | .34 | .51 | 2.02 | 7.83 | 7.02 | 56.10 | 26.00 | 34.73 | 4.57 | 41.41 | 28.02 | 26.00 |

[1] For information on the forest cover on this plot, see table 8.

TABLE 13.—*Mechanical analysis of soil, Plot P49-12* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.14 | 0.35 | 4.23 | 13.52 | 10.34 | 55.90 | 15.52 | 20.83 | 8.23 | 44.19 | 32.06 | 15.52 |
| 2 | .14 | .19 | 3.42 | 19.07 | 16.19 | 49.06 | 11.93 | 16.40 | 8.17 | 54.98 | 24.92 | 11.93 |
| 3 | .10 | .10 | 2.25 | 30.76 | 31.42 | 22.85 | 12.52 | 14.77 | 6.37 | 71.47 | 9.64 | 12.52 |
| 4 | ------ | ------ | 2.18 | 40.04 | 35.06 | 14.38 | 8.34 | 10.58 | 7.35 | 77.80 | 6.51 | 8.34 |
| 5 | ------ | ------ | 1.73 | 40.99 | 35.77 | 15.21 | 6.30 | 8.53 | 6.30 | 82.94 | 4.46 | 6.30 |
| 6 | 1.92 | 1.42 | .88 | 14.46 | 25.98 | 40.56 | 14.78 | 19.03 | 6.17 | 58.19 | 20.86 | 14.78 |

[1] For information on the forest cover on this plot, see table 8.

TABLE 14.—*Mechanical analysis of soil, Plot P49-16* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.13 | 1.95 | 8.78 | 13.84 | 9.70 | 56.24 | 9.36 | 15.07 | 15.31 | 48.25 | 27.08 | 9.36 |
| 2 | .66 | 1.23 | 6.21 | 15.44 | 14.27 | 52.50 | 9.69 | 13.48 | 12.58 | 54.99 | 22.74 | 9.69 |
| 3 | .13 | .38 | 4.50 | 13.26 | 12.04 | 59.28 | 10.41 | 13.06 | 8.59 | 53.86 | 27.14 | 10.41 |
| 4 | .71 | 1.34 | 4.86 | 8.34 | 5.96 | 56.35 | 22.44 | 28.10 | 9.67 | 34.93 | 32.96 | 22.44 |

[1] For information on the forest cover on this plot, see table 4.

TABLE 15.—*Mechanical analysis of soil, Plot P49–20* [1]

[Values represent percentages

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.03 | 0.04 | 4.03 | 15.44 | 10.54 | 58.45 | 11.47 | 16.79 | 8.48 | 49.95 | 30.10 | 11.47 |
| 2 | ------ | .35 | 1.85 | 9.97 | 17.04 | 61.21 | 9.55 | 11.83 | 3.98 | 64.26 | 22.21 | 9.55 |
| 3 | .05 | .12 | 2.13 | 8.90 | 11.74 | 62.40 | 14.66 | 17.96 | 4.55 | 52.50 | 28.29 | 14.66 |
| 4 | ------ | .54 | 5.02 | 20.30 | 21.59 | 47.31 | 5.24 | 8.46 | 10.22 | 70.04 | 14.50 | 5.24 |

[1] For information on the forest cover on this plot, see table 3.

TABLE 16.—*Mechanical analysis of soil, Plot P49–24* [1]

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.05 | 0.39 | 4.93 | 12.61 | 11.34 | 60.81 | 9.87 | 16.66 | 10.03 | 46.57 | 33.53 | 9.87 |
| 2 | ------ | .11 | 1.82 | 11.72 | 13.51 | 58.81 | 14.03 | 19.80 | 4.49 | 51.98 | 29.50 | 14.03 |
| 3 | .29 | 1.05 | 9.08 | 21.82 | 10.48 | 44.09 | 13.19 | 16.96 | 18.01 | 44.09 | 24.71 | 13.19 |
| 4 | .15 | 1.64 | 16.52 | 20.55 | 5.26 | 37.40 | 18.48 | 25.41 | 27.77 | 27.92 | 25.83 | 18.48 |
| 5 | 1.51 | 4.70 | 40.46 | 42.97 | 4.26 | 2.48 | 3.62 | 5.22 | 68.05 | 24.72 | 3.61 | 3.62 |

[1] For information on the forest cover on this plot, see table 6.

TABLE 17.—*Mechanical analysis of soil, Plot P49–29*

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | ------ | 0.48 | 4.19 | 16.02 | 11.31 | 57.15 | 10.85 | 16.17 | 8.14 | 52.76 | 28.25 | 10.85 |
| 2 | 0.17 | .29 | 2.63 | 11.40 | 8.40 | 65.05 | 12.06 | 15.39 | 5.93 | 51.22 | 30.79 | 12.06 |
| 3 | .34 | .67 | .59 | 8.87 | 6.41 | 71.12 | 12.00 | 15.32 | 4.44 | 52.92 | 30.64 | 12.00 |
| 4 | .18 | .42 | 1.03 | 2.56 | 3.37 | 82.66 | 9.78 | 14.06 | 2.41 | 49.49 | 38.32 | 9.78 |
| 5 | 5.26 | 6.12 | 13.22 | 18.12 | 11.45 | 36.13 | 9.70 | 12.93 | 30.27 | 41.25 | 18.78 | 9.70 |

TABLE 18.—*Mechanical analysis of soil, Plot P49–33*

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.08 | 0.42 | 3.18 | 13.17 | 9.50 | 60.73 | 12.92 | 17.63 | 6.51 | 49.62 | 30.95 | 12.92 |
| 2 | .11 | .72 | 3.41 | 10.80 | 8.75 | 63.12 | 13.09 | 17.87 | 6.76 | 50.85 | 29.30 | 13.09 |
| 3 | .16 | .17 | .75 | 3.78 | 4.39 | 80.90 | 9.85 | 14.58 | 2.18 | 52.86 | 35.11 | 9.85 |
| 4 | .07 | .35 | 1.00 | 2.61 | 5.82 | 81.43 | 8.72 | 13.38 | 2.07 | 56.58 | 32.63 | 8.72 |
| 5 | 10.89 | 13.22 | 15.44 | 15.15 | 6.87 | 30.79 | 7.64 | 10.25 | 45.28 | 30.80 | 16.28 | 7.64 |

TABLE 19.—*Mechanical analysis of soil, Plot P49–37*

[Values represent percentages]

| Horizon | American system (fractions mm.) | | | | | | | | International system (fractions mm.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0–1.0 | 1.0–0.5 | 0.5–0.25 | 0.25–0.10 | 0.10–0.05 | 0.05–0.002 | <0.002 | <0.005 | 2.0–0.2 | 0.2–0.02 | 0.02–0.002 | <0.002 |
| 1 | 0.10 | 0.53 | 5.32 | 16.43 | 10.59 | 56.15 | 10.88 | 16.21 | 10.03 | 50.78 | 28.31 | 10.88 |
| 2 | .07 | .42 | 4.00 | 13.05 | 9.18 | 60.12 | 13.07 | 17.43 | 8.67 | 47.55 | 30.71 | 13.07 |
| 3 | .21 | .85 | 4.96 | 10.95 | 7.74 | 64.46 | 10.83 | 15.12 | 9.83 | 50.11 | 29.23 | 10.83 |
| 4 | .32 | 1.35 | 6.51 | 9.53 | 8.31 | 66.26 | 7.72 | 13.40 | 11.92 | 51.73 | 28.63 | 7.72 |
| 5 | 1.83 | 7.29 | 30.18 | 27.94 | 7.62 | 19.51 | 5.63 | 7.24 | 51.37 | 31.75 | 8.25 | 5.63 |

TABLE 20.—*Moisture equivalents of soils*

[Values represent percentage of dry weight]

| Horizon | Plot | | | |
|---|---|---|---|---|
| | P49–24 | P49–37 | P49–33 | P49–29 |
| 1 | 29.41 | 32.88 | 27.30 | 33.45 |
| 2 | 32.52 | 32.22 | 26.40 | 37.08 |
| 3 | 34.22 | 24.32 | 22.40 | 30.10 |
| 4 | 53.74 | 18.76 | 17.70 | 24.06 |
| 5 | 3.15 | 5.45 | 9.53 | 11.40 |
| I | ------ | 34.68 | 27.42–26.50 | 26.73 |
| II | ------ | 48.15 | 27.42–24.78 | 27.12 |
| III | ------ | ------ | ------ | ------ |
| IV | ------ | 29.88 | 27.79–28.68 | 30.92 |

TABLE 21.—*Hydrogen-ion concentration (pH) of soils* [1]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49–12 | P49–1 | P49–5 | P49–9 | P49–16 | P49–20 | P49–24 | P49–37 | P49–33 | P49–29 |
| $1_0$ | 4.02 | 4.57 | 4.64 | 4.44 | 4.30 | 4.49 | 4.44 | 5.03 | 4.31 | 4.87 |
| 1 | 4.21 | 4.68 | 5.09 | 4.47 | 4.31 | 4.53 | 5.42 | 4.93 | 4.96 | 4.81 |
| 2 | 5.38 | 5.45 | 5.16 | 5.25 | 5.47 | 5.89 | 5.79 | 5.45 | 5.68 | 5.48 |
| 3 | 5.77 | 5.68 | 5.82 | 5.70 | 6.14 | 5.94 | 5.90 | 5.61 | 5.55 | 5.93 |
| 4 | 5.75 | 5.83 | 5.52 | 6.22 | 6.35 | 5.71 | 5.70 | 5.37 | 5.44 | 5.62 |
| 5 | 5.81 | 5.82 | 5.76 | ------ | ------ | ------ | 6.03 | 5.79 | 5.62 | 5.74 |
| 6 | 5.64 | 5.77 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| I | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 6.25 | 6.43 | 6.74 |
| II | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 7.18 | 6.82 | 6.63 |
| III | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 5.78 | 5.19 | 5.52 |
| IV | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 5.70 | 5.84 | 5.96 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.

TABLE 22.—*Organic matter content of soils* [1]

[Values represent loss-on-ignition, percent]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49-12 | P49-1 | P49-5 | P49-9 | P49-16 | P49-20 | P49-24 | P49-37 | P49-33 | P49-29 |
| $1_0$ | 64.56 | 80.23 | 83.53 | 78.82 | 82.50 | 61.06 | 67.24 | 38.55 | 37.52 | 35.38 |
| 1 | 8.98 | 5.47 | 6.35 | 9.74 | 9.58 | 11.24 | 8.56 | 12.83 | 12.16 | 10.96 |
| 2 | 14.96 | 9.28 | 13.77 | 8.58 | 10.60 | 7.19 | 7.57 | 8.13 | 6.14 | 12.29 |
| 3 | 4.59 | 7.49 | 6.15 | 5.26 | 4.03 | 5.58 | 8.62 | 4.19 | 4.13 | 5.74 |
| 4 | 3.41 | 4.78 | 2.58 | 2.61 | 2.08 | 2.37 | 11.22 | 3.18 | 2.96 | 3.52 |
| 5 | 2.80 | 4.77 | 1.97 | | | | 1.52 | 1.75 | 2.28 | 2.06 |
| 6 | 2.71 | 3.02 | | | | | | | | |
| I | | | | | | | | 13.80 | 12.19 | 4.40 |
| II | | | | | | | | 20.47 | 9.47 | 4.16 |
| III | | | | | | | | 13.10 | 8.11 | 7.92 |
| IV | | | | | | | | 9.16 | 6.12 | 5.11 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.

TABLE 23.—*Total nitrogen content of soils* [1]

[Values in percentage of dry weight]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49-12 | P49-1 | P49-5 | P49-9 | P49-16 | P49-20 | P49-24 | P49-37 | P49-33 | P49-29 |
| $1_0$ | 1.021 | 1.268 | 1.294 | 1.425 | 1.356 | 1.241 | 1.300 | 0.633 | 0.609 | 0.443 |
| 1 | .162 | .118 | .109 | .159 | .162 | .181 | .161 | .267 | .164 | .197 |
| 2 | .237 | .145 | .245 | .121 | .177 | .104 | .106 | .133 | .075 | .275 |
| 3 | .067 | .125 | .089 | .078 | .066 | .079 | .138 | .057 | .047 | .075 |
| 4 | .045 | (2) | .003 | (2) | .022 | .034 | .234 | .040 | .034 | .046 |
| 5 | .041 | .001 | .020 | | | | .016 | .018 | .022 | .022 |
| 6 | .028 | .042 | | | | | | | | |
| I | | | | | | | | .034 | .264 | .083 |
| II | | | | | | | | .623 | .230 | .094 |
| III | | | | | | | | .304 | .115 | .106 |
| IV | | | | | | | | .163 | .086 | .069 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.
[2] Trace.

TABLE 24.—*Readily available phosphorus content of soils* [1]

[Values represent parts per million of soil]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49-12 | P49-1 | P49-5 | P49-9 | P49-16 | P49-20 | P49-24 | P49-37 | P49-33 | P49-29 |
| $1_0$ | 131 | 205 | 258 | 227 | 375 | 272 | 115 | 71 | 65 | 75 |
| 1 | 4 | 39 | 60 | 19 | 46 | 65 | 1 | 22 | 41 | 48 |
| 2 | (2) | (2) | 38 | (2) | 6 | 2 | (2) | (2) | 11 | 11 |
| 3 | 2 | (2) | 2 | 2 | 13 | 9 | 2 | 2 | 9 | 1 |
| 4 | 6 | 16 | 65 | 147 | 274 | 76 | 3 | 11 | 14 | 7 |
| 5 | 10 | 11 | 106 | | | | 25 | 38 | 85 | 32 |
| 6 | 51 | 68 | | | | | | | | |
| I | | | | | | | | 248 | 172 | 60 |
| II | | | | | | | | 725 | 272 | 55 |
| III | | | | | | | | 39 | 56 | 45 |
| IV | | | | | | | | 4 | 10 | 2 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.
[2] Trace.

TABLE 25.—*Exchangeable potassium in soils* [1]

[Values are percentages of dry weight]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49-12 | P49-1 | P49-5 | P49-9 | P49-16 | P49-20 | P49-24 | P49-37 | P49-33 | P49-29 |
| $1_0$ | 0.0385 | 0.0494 | 0.0427 | 0.0700 | 0.1619 | 0.0566 | 0.0443 | 0.0337 | 0.0268 | 0.0340 |
| 1 | .0120 | .0092 | .0089 | .0125 | .0089 | .0109 | .0071 | .0151 | .0139 | .0242 |
| 2 | .0129 | .0106 | .0174 | .0117 | .0107 | .0085 | .0082 | .0078 | .0081 | .0163 |
| 3 | .0104 | .0140 | .0122 | .0095 | .0091 | .0072 | .0102 | .0062 | .0088 | .0098 |
| 4 | .0081 | .0123 | .0077 | .0038 | .0052 | .0063 | .0103 | .0063 | .0086 | .0098 |
| 5 | .0099 | .0097 | .0048 | | | | .0036 | .0055 | .0066 | .0060 |
| 6 | .0067 | .0085 | | | | | | | | |
| I | | | | | | | | .0252 | .0276 | .0364 |
| II | | | | | | | | .0316 | .0340 | .0331 |
| III | | | | | | | | .0216 | .0138 | .0241 |
| IV | | | | | | | | .0178 | .0143 | .0122 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.

TABLE 26.—*Exchangeable calcium in soils* [1]

[Values are percentages of dry weight]

| Horizon | Plot | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P49-12 | P49-1 | P49-5 | P49-9 | P49-16 | P49-20 | P49-24 | P49-37 | P49-33 | P49-29 |
| $1_0$ | 0.1283 | 0.2390 | 0.1933 | 0.2685 | 0.5072 | 0.1808 | 0.1924 | 0.2915 | 0.1062 | 0.2892 |
| 1 | .0348 | .0512 | .0510 | .0413 | .0408 | .0477 | .0536 | .0582 | .0716 | .0677 |
| 2 | .1073 | .0500 | .0321 | .0330 | .0818 | .0541 | .0480 | .0257 | .0156 | .0500 |
| 3 | .0329 | .0315 | .0266 | .0413 | .0332 | .0357 | .0488 | .0146 | .0112 | .0268 |
| 4 | .0229 | .0425 | .0167 | .1664 | .1044 | .0161 | .0531 | .0107 | .0129 | .0119 |
| 5 | .0219 | .0442 | .0535 | | | | .0146 | .0101 | .0136 | .0072 |
| 6 | .0675 | .0270 | | | | | | | | |
| I | | | | | | | | .3666 | .2380 | .0564 |
| II | | | | | | | | .7426 | .2623 | .0763 |
| III | | | | | | | | .2056 | .0552 | .0335 |
| IV | | | | | | | | .0643 | .0326 | .0182 |

[1] For information on the forest cover on these plots, see tables 3, 4, 6, and 8.

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